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SAMPLING RANGES BY THE LINE INTERCEPTION METHOD

PLANT COVER—COMPOSITION—DENSITY—DEGREE OF FORAGE USE

By R. H. Canfield
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> "Until the phenomena of any branch of knowledge have been submitted to measurement and number, it cannot assume the status and dignity of a science."
> —Galton

1/ Maintained by the Forest Service, U. S. Department of Agriculture, for the States of Arizona, New Mexico, and west Texas, with headquarters at Tucson, Ariz.

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INTRODUCTION

During the past 3 years the Range Research staff of the Southwestern Forest and Range Experiment Station has conducted tests in sampling density and composition of range vegetation by the line interception method. These trials have included the sampling of numerous small experimental plots, several experimental range pastures, and two large national-forest allotments.

One of the advantages obtained through these tests was the development of standard practices for use of this method in the field. With each succeeding experience in the field work and in the analysis of such data as these projects produced as a guide, the method has been revised and extended. By this means the procedure followed in applying the line interception method of sampling plant density and composition was gradually molded to fit the requirements of many different phases in range research. Special attention was given to forage-plant inventory and the measurement of forage use. In this manner the field technique used in sampling forage composition, density, and grazing use has been brought to a stage of workability that appears to insure uniformly good results. In order that the methods used may be made available to other workers, a description of the line interception method and procedure followed in the testing of data obtained therefrom is herewith presented.

Description of the Method

The line interception method may be described as a procedure for sampling vegetation based on the measurement of the intercept of all plants occurring on the courses of randomly located lines of equal length.2/ The manner in which the lines are laid out and the included plants measured in the field is illustrated in the drawing reproduced in figure 1. The first step in this process of measuring plants is to mark out the line on which the measurements are to be made. It is accomplished in the following way: A multiple-strand wire 1/16 inch or less in diameter, of the required length is used for this purpose. This wire, when stretched out on the ground under as much tension as can be exerted with the hands, marks the line or course of the sampling unit. The wire is held in place under tension by inserting iron pins through the 1-inch rings (shown in fig. 1) attached at both ends of the wire and then driving these pins securely into the ground.

Any standard system of measurement is acceptable for use in the measurement of plants. In our work the foot measure—scaled in feet, tenths, and hundredths—has been used throughout and has proved to be entirely satisfactory. If the metric system is used, it should be applied throughout

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2/ Canfield, R. H. "Application of the line interception method in sampling range vegetation" Jour. Forestry 39(4): 388-394, 1941.

the sampling operation.

Measurements of vegetation are made on the course of this line within its vertical plane and parallel to it. Each plant growing on the line is measured on the line intercept in a way that will give the numerical value of the ground that is completely occupied by plants under the line. These measurements are recorded with regard to species and forage classes. A single line is called a <u>sampling unit</u>. A predetermined number of sampling units constitutes a <u>sample</u>, and the average obtained from all the sampling units included in a sample is the <u>sample mean</u>.

The objective in sampling is to obtain the mean of a sample which will provide a basis for an estimate of the plant population for the area from which the sample is taken. Usually composition, forage use, and density are the chief items of interest. Vegetational composition or forage use, expressed in percent of each species or forage class represented, is computed in the usual manner. On the other hand, <u>absolute density</u> is expressed in terms of percent of ground cover and represents the relative amount of ground space completely occupied by herbaceous plants on the average sampling unit.

Actual area of the ground surface occupied by all vegetation growing within a range unit may be calculated by multiplying the total area of the plot, pasture, or allotment by the percent of ground occupied by vegetation on the average sampling unit. When samples obtained by the line interception method conform to standard designs for sampling, the degree of reliability of any mean or estimate made therefrom may be calculated by established mathematical procedures.

PART I.
INSTRUCTIONS FOR SAMPLING RANGE VEGETATION

Basic Elements of Working Plan

When this method is applied in sampling a range area for composition and density or the degree of grazing use of forage plants, five essential operations in the plan of procedure must be clearly defined in advance. These points, named in the order that they will occur, are:

1. Measurement.—How the plants are to be measured, the unit of measurement to be employed (centimeters or hundredth-foot) and in what way the data are to be recorded: (a) in sampling density and composition for the forage-plant inventory, and (b) in sampling grazing use for the utilization survey.

2. Sample size.—Length of sampling unit to be used and the number of sampling units to be included in the sample.

3. Distribution of sampling units.—Randomization and procedure for locating sampling units on a field map.

4. Field work.—Crew, equipment, and instructions in field procedure.

5. Analysis of data.—Procedure to be followed in the compilation and analysis of data.

Measurement of Plant Density and Composition

All plants intercepted by the line are measured in the manner illustrated in figure 1. The upper part of this sketch (fig. 1, "A") shows a segment of a sampling unit as it would appear to the observer in the field. Note that the positions of the various kinds of vegetation intercepted by the line are shown as they would appear on an actual sampling unit in the field. Figure 1, "B", of this drawing is a diagrammatic projection of the ground occupied by the plants, showing in detail the position and the extent of the line intercept for each individual plant. As here illustrated, the intercept of each plant is measured exactly on the course of the line. An estimate of ground cover in terms of total and exclusive occupancy of the ground is the object of these measurements. For this reason small spots of bare ground occurring within tufts are excluded from the measurement if they are large enough to accommodate additional plants. On the other hand, barren spots which are too small to admit an additional plant are ignored, and the plant is measured as though the entire area included in the intercept were completely occupied. Grasses are measured at ground level (see fig. 1, "C") and include in the intercept the complete coverage of living grass (as defined above) at this point of measurement. If desired, dead grass may be measured and recorded separately.

Weeds are measured at ground level in two ways, depending on the habit of growth. Single-stemmed weeds are measured on the stem diameter, whereas weeds of rosette form are measured on the intercept of the basal leaves. In this way an estimate of the ground surface actually occupied by plants of all these types is arrived at by actual measurement.

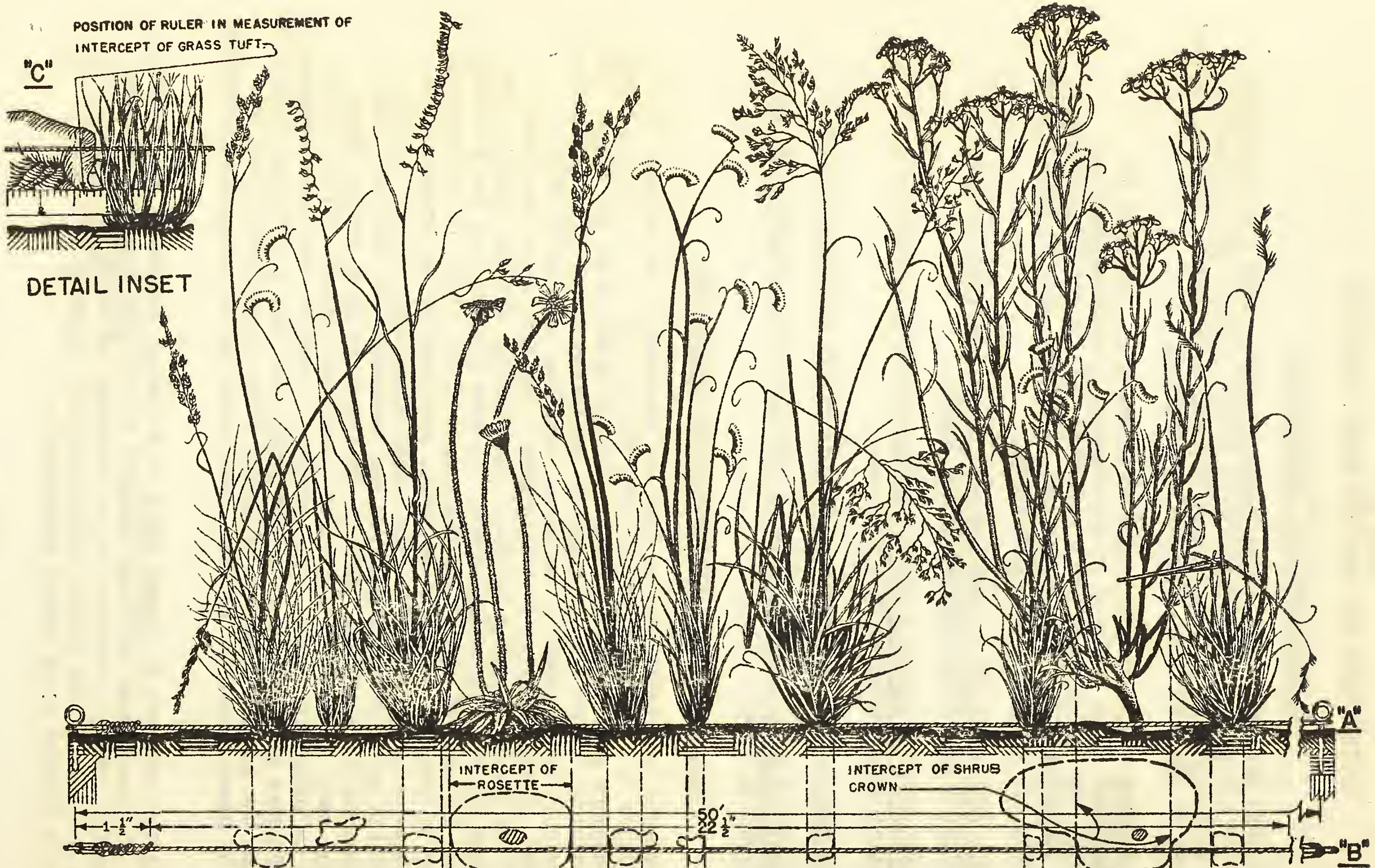


FIGURE 1.—A SEGMENT OF A LINE TRANSECT SHOWING THE MANNER IN WHICH THE VEGETATION IS MEASURED. "A"—AS THE TRANSECT APPEARS TO THE OBSERVER IN THE FIELD. "B"—A DIAGRAMATIC PROJECTION OF THE INTERCEPTED PORTION OF TUFTS ON THE LINE OF MEASUREMENT. "C"—DETAIL OF MEASURING PLANT AT GROUND LEVEL.

Browse plants, which represent still another class of vegetation, are best measured on the crown spread as intercepted by the vertical projection of the line. The reason for this deviation from the general procedure followed in measuring herbaceous plants is that the measurement of the stem diameters of browse is rarely a measure of the ground this class of plant occupies to the exclusion of other plants. Crown spread, on the other hand, is a valid measurement of browse when it is regarded as occupying a universe above ground and separate from the herbaceous species. And, while it must be admitted that measurements of browse made in this manner are not directly comparable with the grass and weed measurements, it is believed that the relative amount of browse cover is best represented by a measurement of crown spread.

A form suitable for use in recording field data is illustrated in figure 2. It can be made up from letter-size tabulation paper. (Mimeographing is satisfactory.) In using this form the measurement of each plant is recorded in the column under the symbol adopted for the species. The manner in which the data are filled in is also indicated in figure 2. Using this form, each sampling unit usually is recorded on a separate sheet. The totals of the measurements made on each sampling unit comprise one observation.

Measurement of Grazing Use

The purpose of this section is to describe the procedure by which the degree of range utilization on a small sample taken within a grazing allotment or pasture can be measured in a manner that will provide a reliable basis for an estimate of the mean grazing use for the entire range unit. The foundation of the method is the concept that the degree (and intensity) of grazing use is truly reflected by a combination of grazed stubble heights and the amount of ungrazed grass left on the ground at the end of the grazing season or year.

Basically, the proposed way of measuring grazing use is an extension of the line interception method. In this case the line interception method has been modified to include stubble-height measurements, and a stubble-height classification has been added. The procedure is as follows: The utilization sample is comprised of measurements made on a number of randomly distributed lines (sampling units) of equal length. Stubble heights and ground cover of each plant intercepted by this line are measured on the line. (See fig. 3.) Each stubble-height measurement is placed in a stubble-height class and the measurement of the ground occupied under the line by the plant or portion of a plant so grazed is recorded in the proper column of a suitably designed field form.

The manner in which field measurements are made is illustrated in figure 3. Note the line "A" pegged in place. This line marks out the course and length of the sampling unit. The section of the drawing marked "B" shows a diagrammatic projection of the basal perimeter of each plant and indicates the intercept at normal ground level of each tuft to be measured on the line. Stubble heights are measured from the ground level vertically in inches on the line and in a plane perpendicular to it. (Erosion levels between plants are regarded as subnormal levels.) The basal intercept of each stubble-height class is measured and recorded according to the respective height class. This operation may involve more than one class of use on an individual tuft.

Field Record Form

Project Forage plant inventory Date 6/12/42

Sampling Unit No. 4 Examiners Lindsey and Haskell

Location NW¼ sec. 8 T19S, R14E Forage type Foothill

(Record all measurements in hundredths of a foot)

	Grasses					Weeds			Browse		
	(Plant symbols)										
	Ber	Bfi	Adi	Bro	Bch	Sel	Kgr		Pch	Cer	
	6	1	8	7	3	3	1		72	80	
	4	5	2	12	2	7	1		84	24	
	1		6	16	4				68		
			7	21	6						
				9							
				2							
Total (feet)											

Figure 2.—Sample field record form used in recording samples of density and composition of plant cover. The totals constitute an observation. Specific jobs may require additional space for notation of incidental information at top of form.

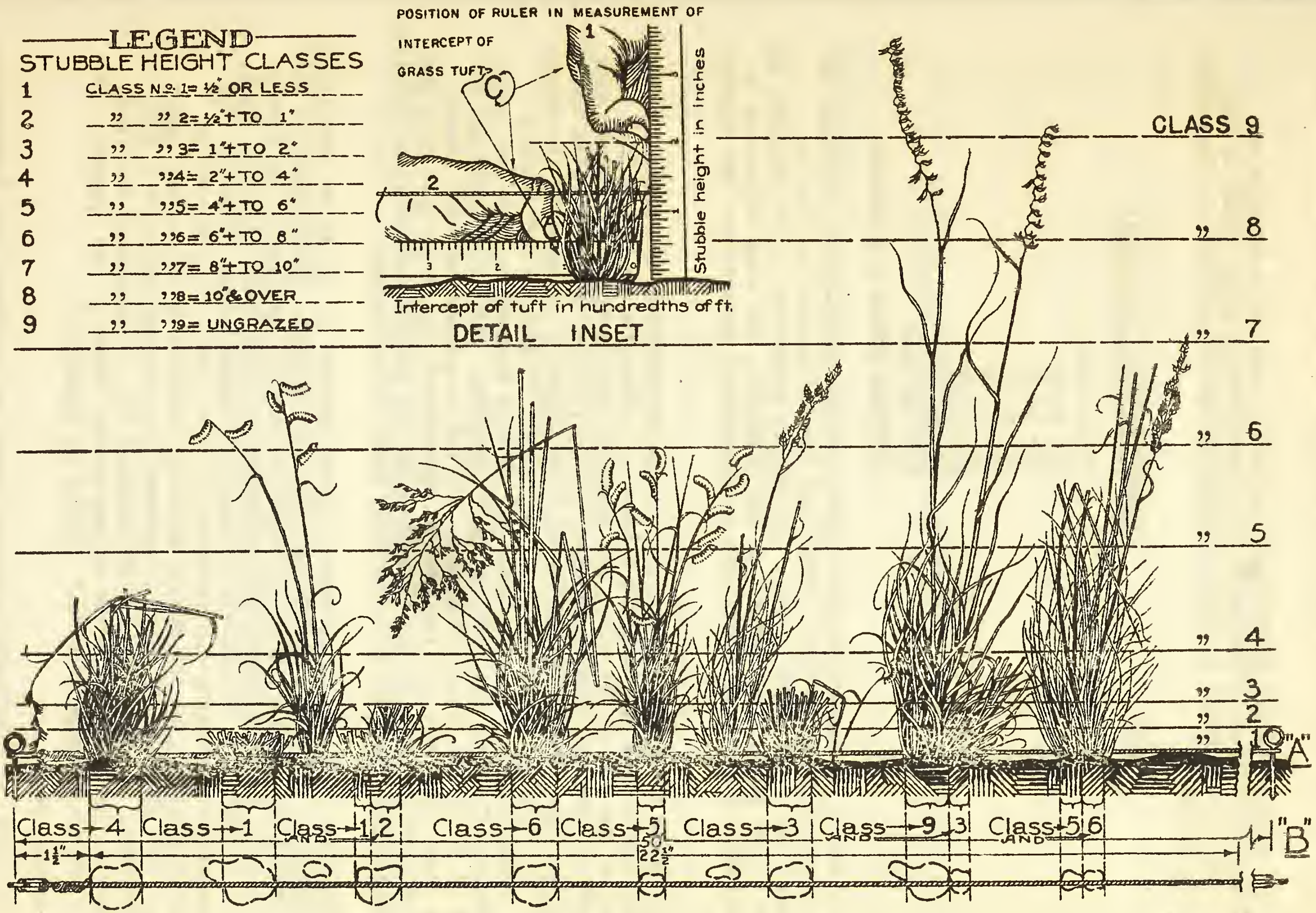


FIG. 3.—"A"—A SEGMENT OF A LINE TRANSECT SHOWING THE POSITION OF THE LINE WITH REGARD TO THE VEGETATION. "B"—A PROJECTION OF THE GROUND OCCUPIED BY EACH TUFT AND STUBBLE HEIGHT CLASS. "C"— A DETAILED DRAWING ILLUSTRATING THE MANNER IN WHICH THE HEIGHT AND DENSITY MEASUREMENTS ARE MADE.

A sample of the form used in recording field measurements is presented in figure 4.

The stubble-height classification herein used as an example was devised by Matt Culley of the Santa Rita Experimental Range where it has proved quite satisfactory in field utilization surveys.[3] Culley's classification is as follows:

Class	Stubble Height (in inches)
1	$\frac{1}{2}$" or less
2	$\frac{1}{2}$"+ to 1"
3	1"+ to 2"
4	2"+ to 4"
5	4"+ to 6"
6	6"+ to 8"
7	8"+ to 10"
8	10"+ or over
9	Ungrazed grass, any height

It should be understood that these stubble-height-class intervals are more or less arbitrary in their limits and may be adjusted to fit the requirements of other range areas. The example presented is satisfactory for a number of the grama grass ranges of the Southwest, but some adjustment in class intervals may be necessary when coarse-stemmed grasses are the dominant plants.

In order to obtain a clear idea of how measurements are actually made, visualize figure 3 as representing a line to be measured in the field. Beginning at one end of the wire, the examiner would proceed to measure each grass tuft in turn as it is encountered in his progress along the line toward the opposite end. The "Detailed Sketch C" of figure 3 illustrates the manner in which the ruler is handled in the measurement of density and stubble height. Measurements of ground cover are made in hundredths of a foot with one-hundredth of a foot the smallest unit recorded. Stubble heights may be measured in inches or tenths of a foot. Either is proper provided always that the class intervals and the unit of measurement are compatible with conditions of grazing use. In this illustration the stubble-height-class interval is in inches, and the class in which they occur is indicated.

The first tuft to be measured is grass species 1. It is so identified by the examiner. This particular plant has been grazed. Measurement of its stubble height determines the height class to which it belongs. The grazed stubble of this plant as illustrated measures to scale about $2\frac{1}{2}$ inches high, placing it in the 2- to 4-inch class which is stubble-height class 4. The second measurement involves the intercept of the plant. It consists of measuring at <u>ground level</u> the ground actually occupied by this plant <u>under the line</u>. The intercept of plant 1 measures six one-hundredths of a foot. This measurement is called out by the measurer and is entered on the field record form by the recorder in the column headed "Class 4" and opposite the written-in species designation "1." (Refer to figure 4.)

3/ Culley, Matt J. "Utilization survey report on the Santa Rita Experimental Range" June 30, 1939 /Unpub. data in files Southwestern Forest and Range Expt. Sta./

Field Record Form

Sampling Unit No. 14 Project Pasture 6-A Date 6/10/41

Location NW¼ sec. 20 T18S, R15E Examiners Lindsey and Haskell

Forage type Mesa grassland Time 9:55 to 10:10

Cultural or topographic features: Fence 15 ch. W., water 45 ch. E., slope 10% SW.

Grass species	Dead sod	Stubble-height classes recorded in hundredths of a foot									Height ungrazed
		0"-½" 1	½"+-1" 2	1"+-2" 3	2"+-4" 4	4"+-6" 5	6"+-8" 6	8"+-10" 7	10"+ 8	Ungrazed 9	In.
#1				20	6				2	9	12
				5		3	10				
Total:											
#2		4		10	20	5	3	4		12	16
Total:											
#3		2	4	1	5			7	6	4	7
Total:											
Grand total: (feet)		0.06	0.04	0.36	0.31	0.08	0.13	0.11	0.08	0.25	

Figure 4.—A sample record form on which the manner of recording field data is indicated. Each of the totals in this table constitutes an observation. In actual practice the form is extended as many columns to the right as are necessary to accommodate weeds and browse measurements.

The next grass in line, designated as species 2, is grazed to a class 1 stubble height, with an intercept of four one-hundredths of a foot. A different condition of grazing use is encountered in the third plant from the left margin. This plant, which is species 3, has been grazed at two different heights. Cases such as this in which two or more height classes are involved are handled by making separate measurements for the parts of the intercept under each of the respective height classes. These measurements would be entered on the form (fig. 4) as class 1, two one-hundredths of a foot, and class 2, four one-hundredths of a foot.

The intercept of ungrazed grasses—irrespective of height—is recorded in class 9. Individual maximum height of ungrazed plants is measured and entered in the space following the column set up on the form for class 9. These measurements are eventually converted to weighted average height for the species.

Weeds and browse occurring in a grass range as a general rule are not included in the estimate of the degree of range use. However, they may be taken into account in the estimate of the plant cover and composition. Weeds are measured as described in a previous section.

Required Size of Sample

Length of Sampling Units

In the process of sampling for any purpose by this method a line of predetermined length constitutes the sampling unit. What the length of this line should be to give the best results will vary with the density, the degree of uniformity in composition and distribution of the plant cover, and, of course, the degree of evenness in the distribution of grazing use when the measurement of utilization is involved. The length of line (sampling unit) required to sample a range area may be determined in the field with a fair degree of accuracy by rule-of-thumb. Two such rules, based on experience with southwestern ranges, are: (1) the length of line that can be marked out, measured, and recorded by two reasonably efficient men in a 15-minute period on the average; and (2) ordinarily a 100-foot line is preferred in sampling areas supporting less than 5 percent (measured) ground cover, whereas a 50-foot line has proved adequate for sampling vegetation of 5 to 15 percent (measured) ground cover. Apparently the sampling unit of the proper length to adequately sample forage cover will also prove adequate in sampling the degree of grazing use occurring thereon. As a further index to sampling-unit length requirement, it has been demonstrated in the field that it is not economical to attempt the substitution of a greater number of 50-foot for the 100-foot sampling units nor a greater number of 25-foot sampling units for the 50-foot in sampling semidesert grassland ranges. With the greater number of shorter sampling units, the incidental increase in travel time and other overhead is too great. When the method is applied in sampling experimental plots, the length of sampling unit used is limited by the dimensions of the plot under consideration.

Number of Sampling Units

The number of sampling units of a predetermined length that may be required to obtain an adequate forage inventory sample is directly dependent upon the uniformity of the vegetation with regard to density, composition,

and distribution of species and, in addition, when sampling utilization, it is also dependent upon the degree of uniformity in the distribution of grazing use. These characteristics of a sampling area usually may not be known in advance of the sampling operation. However, experience with similar areas of vegetation is a fairly reliable guide. Pastures on which the plant cover and grazing use are moderately uniform have been sampled with as few as 16 sampling units. Under similar conditions, range allotments containing as much as a township of land have been sampled successfully with as few as two sampling units per standard G. L. O. section (640 acres). These figures for sample size are cited as possible minimum requirements. In cases of extreme variability in either vegetation or grazing use it may be necessary to take a larger number of sampling units.

Once we have a small sample it is possible to compute with a reasonable degree of certainty whether or not the sample mean is a poor estimate of actual conditions. If the data from the first sampling trial should fall short of the desired degree of precision, this fault may be remedied by going back into the field and measuring additional sampling units. An estimate of the number of sampling units needed to complete the sample may be computed in the field from data obtained in the exploratory sample. In this respect mathematicians have devised ways for testing the reliability of a sample mean. With the data from the exploratory sample at hand, it is no longer necessary to guess the size of the sample required to provide an estimate of known reliability. A discussion of the reliability of the sample mean and the calculations to determine whether or not additional observations are necessary will be presented later.

Designs for Random Distribution of Sampling Units

Randomness is a prerequisite for mathematical analysis of sampling data. The practical reasons for this requirement are: (1) A prescribed degree of randomness in the selection of material to be included in a sample is regarded generally as essential to the sampling procedure in that it eliminates from the small sample the personal element which may be introduced therein by conscious choice. (2) Randomness also serves to equalize the effects of hidden influences such as differences in soil fertility and other variable factors not readily detectable in the sample by ordinary observation.

A random distribution of sampling units may be obtained in a number of ways. The most common designs are the purely random sample, the stratified sample, and the representative sample. A description of each design is presented in the following paragraphs.

The Purely Random Sample

A sample of this type is obtained when no restrictions are imposed as to place of sampling other than the bounds of the area being sampled. All sampling-unit locations must be chosen by pure chance. Thus, without any restrictions whatsoever, all possible sampling-unit locations representing the good, the poor, and the average conditions existing within the area being sampled have an independent and proportionately equal chance of being selected each time a random choice is made. By so doing, the laws of chance are permitted to operate freely in the selection and distribution of

measurements of plants and conditions included within the scope of the sample. When no clearly defined, widely divergent regions of different vegetation types are apparent, or suspected, the purely random sample is preferred. In a sample of this type each and every plant species and each separate degree of grazing use or other conditions should have an equal and independent chance of being represented in the sample according to its proportionate frequency and abundance in the plant population, provided that a sufficient number of observations are made.

The Stratified Sample

A stratified sample rather than a strictly random one often is preferred in sampling range vegetation where visible differences in the character of vegetation on different areas are delimited by relatively clear-cut lines; for example, when differences such as abrupt changes in the character of vegetation or in the topographic features are present. In such cases where distinct divisions of the range exist, the plants so delimited are regarded as separate plant populations, and it is frequently advisable to accept the dividing lines and to sample each resultant area separately, i. e., stratified sampling. The procedure followed in the internal distribution of the sampling units when stratified sampling is employed is to treat each division as a separate sampling area. In so doing the same procedure as has been described for the purely random method is applied to each separated part or stratum within the area.

The Representative Sample

Another method which is now coming into general use is called representative sampling. It is a method that imposes greater restrictions on the distribution of sampling units than does the purely random sampling method. The ordinary procedure is to subdivide a map of the area into blocks of equal size, allot an equal number of sampling units to each block or compartment, and then to obtain (by a random process repeated for each block) a distribution of the sampling-unit locations within each block. The allowable block minimum number of observations is two sampling units per block; a greater number is desirable and sometimes necessary. When the representative sampling method is used, the sampling units are distributed more evenly over the entire area than might be expected in a purely random sample. This even spread of sampling units is especially desirable in areas wherein the degree of grazing use is influenced and the plant cover in turn affected by such factors as the location of water developments, salt grounds, or adjacent roads and trails, none of which in any degree is distributed by chance. The greater the differences between blocks the more efficient this method becomes. The favorable psychological effect of the even distribution of sampling units over the entire area obtained by this method should not be underrated.

Selection of Sampling-Unit Locations

The operation of determining sampling-unit locations by random may be accomplished in many ways.

Any method of selection in which pure chance is allowed will insure randomness. Complete randomness can occur only when each and every possible sampling unit has an equal and independent chance of being selected each time a choice is made. Numbered cards or beans may be drawn at random out of a

hat or bag when the possible locations are few in number, but when a large area containing many possible locations for sampling units is to be sampled, either of these methods would be too tedious. As an example: When 1 foot laterally or longitudinally is set up as the smallest interval between the beginning points of different sampling units, a section of land contains the astounding number of 27,619,680 possible 50-foot transect locations. When numbers of possible chances as great as this or greater are involved, the work of preparing a numbered card or bean for each possible location is obviously too great to be considered feasible. Even small packs of cards or bags of beans are not always easy to manipulate because the cards must be reshuffled or the beans mixed anew prior to each successive selection in order to insure complete randomness.

A most convenient method of selecting random points within a large universe is accomplished through the use of a table of random numbers constructed for this specific purpose.4/ In such tables (see table 1) random numbers containing two digits are arranged vertically in columns and horizontally in lines.

Table 1.—A small simulated section of a standard table containing nonrandom numbers but showing the manner in which a table of random numbers is arranged.1/ Numbers used as illustrations in our example are underscored.

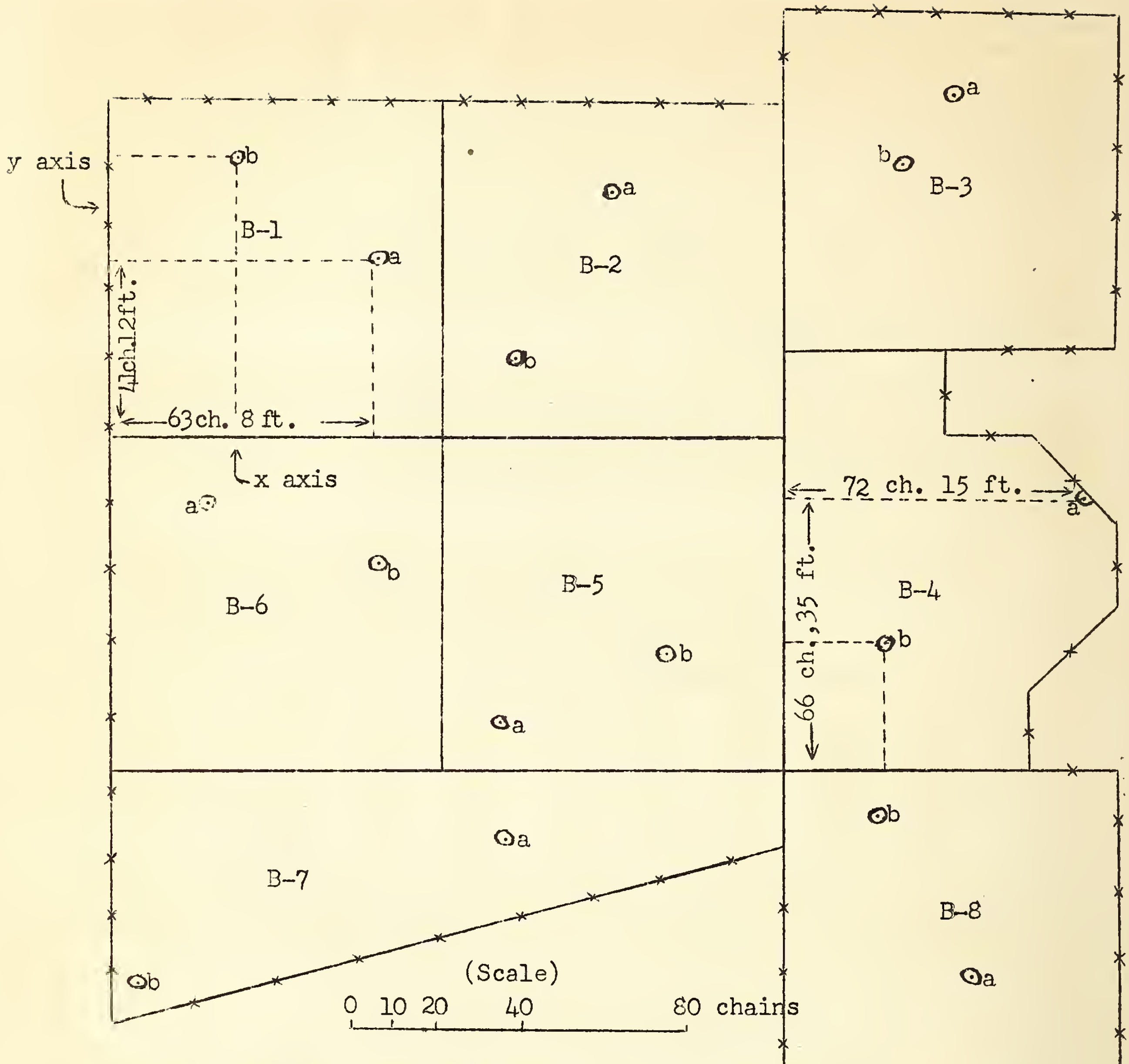
		(1)					(2)		
96	75	<u>12</u>	38	30	95	60	78	46	75
83	91	<u>53</u>	81	08	99	17	43	48	76
92	74	79	78	03	<u>63</u>	62	01	61	16
<u>42</u>	82	81	85	54	<u>78</u>	59	50	88	92
<u>67</u>	73	18	13	37	<u>08</u>	03	45	15	22

1/ Fisher, R. A. and Yates, F. "Statistical tables for biological, agricultural, and medical research workers" 1938

Locations Within Range Areas Having Regular Boundaries

A satisfactory method which may be used to obtain a random distribution of sampling units within rectangular land areas is described as follows: The randomization is confined to the selection of positions on two coordinate axes. If the map of the area has been subdivided into blocks, as in figure 5, the south and west boundary lines of the blocks serve as coordinates. Otherwise, two lines extending at right angles from a common origin are drawn on the map of the area and these lines utilized as coordinate axes. Obviously, any point within the rectangular field subtended by the lines along the two adjacent sides may be located with reference to the positions of two points, one of which is located on each axis of the coordinates. Randomness of sampling-unit locations is insured by selecting the points on the two axes independently by random.

4/ Should there be no tables of random numbers available, a table of logarithms may be used as a substitute. The last two digits of the logarithm are used in the same manner as indicated for the use of the table of random numbers.



Legend: B=block number; ⊙ = sampling unit location.

Figure 5.—Map of North Pasture showing sampling unit locations. (All locations made with reference to the southwest corners of blocks.)

Block No.	"a" Sampling Units	"b" Sampling Units
1	N. 41 ch. 12 ft., E. 63 ch. 8 ft.	N. 66 ch. 24 ft., E. 30 ch. 9 ft.
2	N. 58 ch. 20 ft., E. 39 ch. 60 ft.	N. 18 ch. 42 ft., E. 16 ch. 35 ft.
3	N. 60 ch. 59 ft., E. 40 ch. 26 ft.	N. 44 ch. 2 ft., E. 27 ch. 61 ft.
4	N. 66 ch. 35 ft., E. 72 ch. 15 ft.	N. 29 ch. 11 ft., E. 25 ch. 1 ft.
5	N. 11 ch. 4 ft., E. 13 ch. 27 ft.	N. 26 ch. 39 ft., E. 51 ch. 49 ft.
6	N. 68 ch. 29 ft., E. 22 ch. 65 ft.	N. 47 ch. 30 ft., E. 62 ch. 21 ft.
7	N. 44 ch. 35 ft., E. 93 ch. 12 ft.	N. 9 ch. 28 ft., E. 6 ch. 13 ft.
8	N. 29 ch. 4 ft., E. 43 ch. 57 ft.	N. 68 ch. 35 ft., E. 21 ch. 58 ft.

In selecting these random points a numbered card or bean may be used to represent each 1-chain unit of distance on the axis and for each of the 66 feet contained within a chain. In the use of a set of random number tables, or for that matter with beans or cards, the south and west boundary lines of each block (figure 5) are visualized as the coordinate x and y axes. Both axes are regarded as being subdivided into 1-chain segments, and these segments numbered consecutively beginning at the axis origin, the number of segments depending on the length in chains of the boundary line designated as the x or y axis. The manner in which a table of random numbers is used is illustrated in figure 5. The y axis, block 1 (B-1) in figure 5 contains 80 chains. The particular chain in which the random point will be located is selected first. In order to do so the book of tables is opened at random and the selection of numbers designating the chain segments begun for the y axis by reading down (or across) the columns until an acceptable random number is found, as explained by following procedure. Since there are but 80 1-chain segments contained in the west line (y axis) of block 1, proceed down the column (see table 1) until a number with a numerical value of 80 or less is encountered. Any whole number from 1 to 80 is acceptable. Suppose after passing over 96, 83, and 92, the acceptable number 42 is encountered. This number designates the 42nd chain on the west line (the y axis) of the section. Now to determine the position on the y axis relative to the 66 feet contained within the 42nd chain; proceeding as before, the next acceptable number must be 66 or less, corresponding to the 66 possible locations at 1-foot intervals contained within the 1-chain range. This number may be 12. Then the point is established on the y axis at exactly 41 chains and 12 feet north of the southwest corner of the section. Thus the exact location of the random point on the y axis is determined. In the same manner the position of the random point on the x axis was established within the 63rd chain at 62 chains and 8 feet east of the southwest corner of the section. See south line, block 1, figure 5. The procedure followed in determining the random point on the x axis is in all respects similar to that used for the selection of the random point on the y axis but with this exception however: a number of feet equal to the length of sampling unit used must be subtracted from the last chain in the series on the x axis. Otherwise the sampling unit may extend beyond the boundary of the block to which it had been allotted. When the position of this random point on the x axis is determined (see block 1, fig. 5), perpendiculars are erected from each point on the x and y axes and the intersection of these perpendicular lines marks the beginning point of the "A" sampling unit alloted to block 1. This location is marked on the field map of the area and the feet and chains of the x and y axes recorded in the location notes. The map and notes are used by the field crew as a guide in establishing the beginning point of the sampling unit. Repeat the procedure for as many sampling units as have been allotted to the block or compartment and for as many blocks as are included in the range unit to be sampled.

Locations in Range Areas or Blocks Having Irregular Boundaries

Frequently pastures, allotments, or other sampling areas with irregular boundaries are encountered. In such cases the irregularity in outside boundaries prevents the subdivision of all of the area into square or rectangular blocks. It is possible, though, to subdivide on the basis of blocks with approximately equal areas. A case of this kind is illustrated in figure 5, blocks 4 and 7. This diagram shows a pasture which has been subdivided into blocks of equal area, but in two instances the blocks are necessarily of irregular shape. Block 4, as an example, is an area containing approximately

640 acres. Scaled distances on the map show the west side to be 100 chains, but the breadth of the plot varies from 41 chains on the north to 80 chains at its central region. For the purpose of illustration, assume that the chain selected by random on the y axis (west line) is the 66th chain and the random number designating the foot within the chain is 35. The point selected on the y axis is then established at 65 chains and 35 feet north of the southwest corner of the block. It is discovered by scaling the distance on the map due east from this 65th chain-35th foot point on a line parallel to the x axis that the breadth of the block at this point is only 73 chains. Evidently there are only 73 possible choices for chain numbers contained inside the boundary at this point. The random number must be selected within the range from 1 to 73 in this case. Suppose the number 73 is selected. This chain is the last in the series with its farther end on the block boundary. Any projection of the sampling unit beyond the limits of the 73d chain will be outside the compartment or block—a condition which may well occur if the full 66 feet of the last chain are included within the range of a random selection. Obviously only the chain footage in excess of the length of the sampling unit can be considered in the random selection within the last chain in a series. When a 50-foot sampling unit is used, the range of feet within the last chain in a series would be 66–50=16. Therefore, only the numbers ranging from 1 to 16 can be considered in the random selection of the beginning point of the sampling unit in this previously selected 73d chain. Suppose the number 15 is selected. In this case the randomly selected distance on the x axis is 72 chains and 15 feet. Another point to be remembered is that the zero feet may be considered only in the first 1-chain segment of a series. In succeeding chains the even chains or zero feet are superimposed on the 66th foot of the preceding one.

Locations Within Small Experimental Plots and Enclosures

In past range work small plots have been a productive source of information concerning the effects of different methods of range management, different intensities of utilization, and comparisons between grazing and nonuse.

In recent years the trend in the establishment of small plots and enclosures has been upward. The Forest Service has increased the number of such plots on both experimental ranges and national forests. Increased use of such plots is also evident in the operations of other Federal land-use agencies—notably the Soil Conservation Service and the Grazing Service. In the Forest Service there is a perceptible trend toward standardization in minimum plot size. Conforming to this trend toward standardization, newly established plots in the Southwest usually include a minimum area of 1 acre. Sampling areas 100 x 100 feet in size are selected within the larger areas. A sample plot of these dimensions is here used as an example in illustrating the method of sampling.

A map of a plot 100 x 100 feet in area is presented in figure 6. As indicated, the plot is divided into two rectangular subplots of equal size by drawing a median line through the center of the area. These subplots are labeled on the map as subplot A and subplot B, respectively. The subplots are then subdivided at right angles to the median line each into five equal areas or blocks of 20 x 50 feet. Blocks in each subplot are numbered 1 to 5 on the map, and the field record sheets are identified with the respective

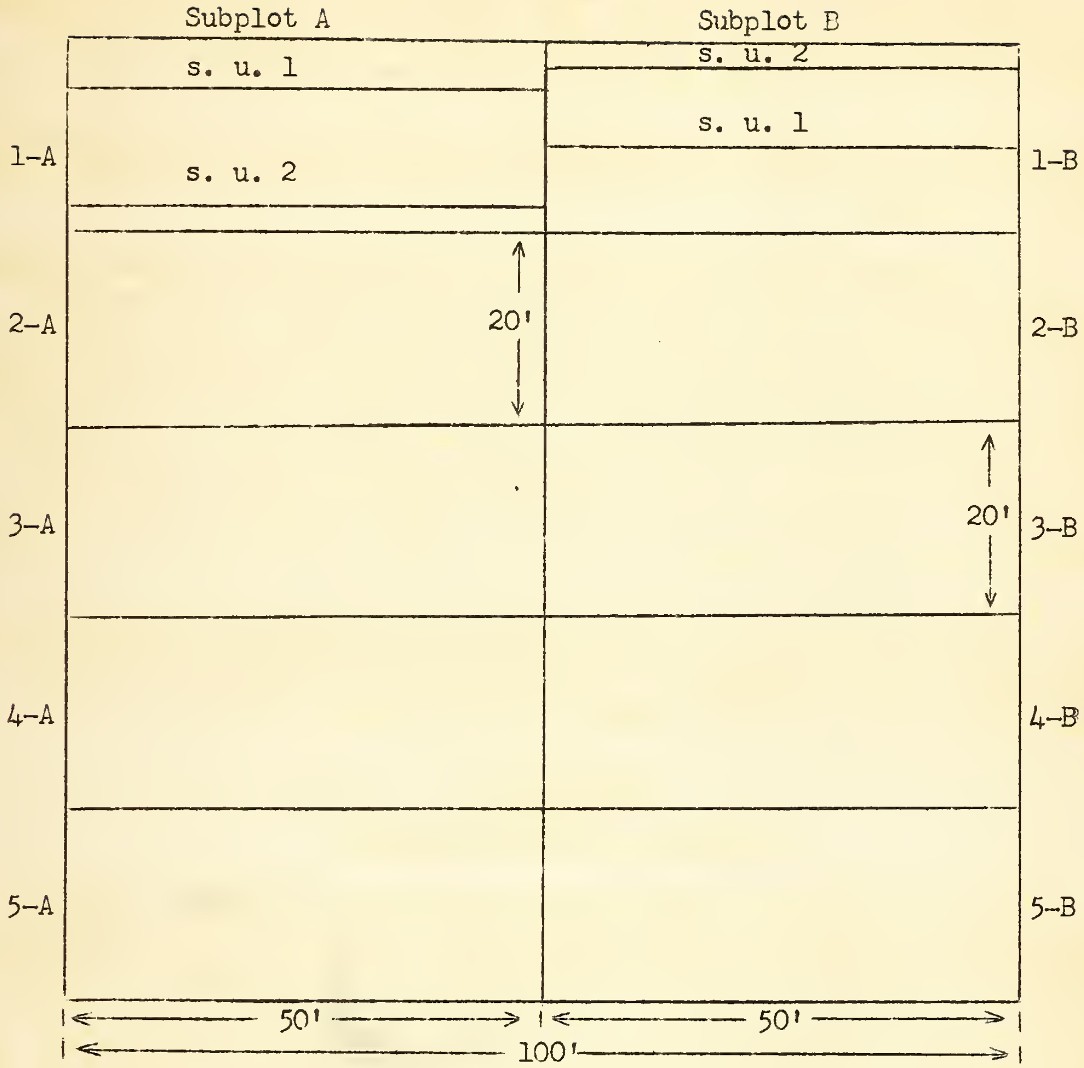


Figure 6.—Showing study plot lay-out for 100 x 100 foot plot. Subplots A and B are stratified at 20-foot intervals, thus dividing the subplots into five 20 x 50 foot compartments. The locations of 50-foot sampling units (s. u.) are indicated in compartments 1-A and 1-B.

blocks by recording the number of the block and the letter designating the subplot in which the sampling unit is located.

Sampling units are run the long way of the 20 x 50-foot block, which will exactly accommodate a 50-foot line. By using 6 inches as the smallest lateral distance between sampling units each block contains 40 possible locations. A separate randomization is made for each block.

Randomization may be accomplished by beginning at the northwest corner of the block and numbering each possible sampling unit in each block from 1 to 40 on the map.

The numerical range from which the selection is made should include all numbers from 1 to 40—exactly the number of possible sampling-unit locations included within a block. The selected number should then be divided by 2. This procedure will convert the sampling-unit number into the distance in feet. The reference point is the northwest corner of the block. Example: Suppose the number 20 is selected by chance, then the sampling unit is located: $\frac{20}{2} = 10$ feet or 10 feet from the northwest corner. If the odd number 31 is selected, then the location is: $\frac{31}{2} = 15$ feet 6 inches from the northwest corner of the block.

While any number of 40 or less sampling units may be allotted to each block, the general practice in range work is to restrict the number to 2 or 4 units each. This procedure for random location of sampling units is repeated for each of the five blocks in each subplot.

Field Work

Field Crew and Its Equipment

Two men constitute a field crew of greatest efficiency. Minimal educational and training requirements for crew members are: At least one member of the crew must be able to recognize the common plants at sight and with some study properly identify all important species likely to be encountered in the sampling area. At least one and preferably both crew members should know how to measure an object with a ruler, have the ability to use a compass, and have training in elementary survey methods sufficient to enable them to pace distances on a compass line and locate a designated point in the field with a reasonable degree of accuracy.

A list of required tools and equipment includes the following: a multiple-strand wire line 1/16 inch in diameter with iron rings 1 inch in diameter attached at each end. (The length of this line, exclusive of rings and fastenings, should be equal to the length of the sampling unit.) Two iron pins 3/8 inch in diameter and pointed for driving, a 5-foot collapsible steel pocket tape measure graduated in feet and inches on one edge and graduated in feet and tenths on the other, a 50-foot tape measure, a hand compass, a protractor, an engineer's scale, a map of the area, pencils, a clip board or tatum holder, and forms for recording the data.

Field Procedure

The exact spot indicated on the map as the beginning point of the sampling unit is located in the field by compass and pacing except for the fractional chain which is measured in feet with a measuring tape.

Field travel time can be reduced somewhat by taking the most direct route from location to location. Obviously a straight line drawn in on the map and extending from the completed sampling unit, or other known point, through the next location is the most direct route. The compass bearing of the course marked by this line on the map is then determined with a protractor. Intervening distance between any two points located on the map may be determined by scale. If distances between sampling-unit locations are traversed by reasonably careful pacing of the required distances on the courses indicated by the compass bearings, the locations of the successive sampling units will be established with sufficient accuracy. Distances may also be measured by car speedometer whenever a car can be used. Errors incidental to such rough survey methods are believed to be compensatory and will in no way disturb the randomness of the sample.

As a further insurance against biased sampling and in order to eliminate the possibility of any degree of personal selection of sampling units, a 50-foot offset to the right (or other prescribed direction) of approach is made from the mapped-in location; that is, each sampling unit is actually laid out and measured on an area that is a 50-foot tape length away from its theoretical location.

The procedure followed in the division of work after the line is pegged down in place is as follows: One man straddles the line, makes the measurements, and calls out the plant name, class, and the length of the intercept as he walks from one plant to the next along the line; the second man records these measurements of the intercepted plants on the field record form under the proper designations for species and classes of plants.

As previously indicated, any standard system of measurement may be used. Commonly used systems are the English and the metric systems. When the English system is used, the measurement scale should be graduated in feet and tenths instead of feet and inches. Measurements made on this scale are read and recorded to the nearest one-hundredth of a foot. Any fraction of the smallest graduation on the feet and tenths scale (i. e., one-hundredth of a foot) that is equal to or greater than one-half this graduate is read and recorded as 1, and any measurement less than one-half the smallest division on the scale is read as zero and disregarded. In practice, few if any small plants are eliminated by this restriction. On the other hand, by this rule all plants—both large and small—are subjected to a consistent policy of measurement. If the metric system is employed, it should be applied throughout the entire sampling operation. Metric measurements are read to the nearest 25 millimeters.

Extreme care should be exercised in maintaining neatness and legibility of field records. Poorly written records are difficult to compile and may become a source of error once they are out of the hand that originally recorded them.

PART II.
TREATMENT OF DATA

Compilation

In order that the practical application of range-plant measurements may be properly evaluated with reference to sampling design, all data hereafter presented as examples represent the sums of information obtained from an actual project. The sample selected for this purpose is of minimum size, and its rated precision is average. No defects have been removed. No embellishments have been added. All of the usually included information concerning composition and density of grass, weeds, and browse cover are presented. However, for brevity, only the data pertaining to perennial grasses are analyzed.

Prior to going into the field, a map of this particular 1,000-acre pasture was divided into eight equal blocks. Then sampling-unit locations were randomly distributed at the rate of two 100-foot sampling units per block and the locations plotted on the map of the area. For the sake of convenience, the sample obtained from this pasture is used in all subsequent operations which demonstrate the treatment of data.

The Forage Inventory Sample

Irrespective of sampling-plan design, the first step is the reduction of data obtained to a more condensed form in order to facilitate subsequent analysis. The beginning of this operation for samples of plant density and composition (the forage inventory) consists in adding, in the manner illustrated in sample field sheets reproduced in example 1, the recorded values that have been entered on the individual field sheets. Field sheet totals represent the sums of the values obtained on a single sampling unit.

Each total contained within the sampling unit is called an observation and is properly regarded as the primary structural unit of the sample. For the purpose of analysis an observation may also include only the sum of the measurements of a single species, or it may embrace a total of all grasses or all of any other class of plants, depending on the purpose or objective in mind.

The second step in the compilation of field data is illustrated in example 2. Samples of grasses only are used in the interest of brevity. This work sheet contains in table form all the sampling-unit totals for grasses which have been transcribed from the sampling-unit field sheets. Each sampling-unit total of each species and class has been entered in this table in the order indicated by its block and sample-unit numbers.

Totals at the bottom of each column in example 2 represent the sums of all the observations for each species and, finally, the grand total of all grasses. The last line in the table contains the averages for each column computed by dividing the total of each column by the number of observations; in this case 16. These sampling-unit averages are generally referred to as the sample means. They represent the estimates of how much ground on the average is occupied by grasses of the different species and for the total of all grasses growing on the average sampling unit. Since our estimate of the pasture is based on the sample, this array of means also represents our best estimate of the average amount of the total ground surface of the pasture that

Field Record Form

Project Range plant inventory Sampling unit length 100 ft.

Block 1 Unit 1 Pasture No. A Date 6-12-41

Location SW¼SW¼sec.27,T18S,R15E Forage type 1 Examiners McK & J. S.

Topography hilltop Slope 0 Fences 25 ch. SE. Water 3 ch. W.

Salt 1 mi. N. Roads 10 ch. Trails 1 ch. Rodent pop. High _ Medium _ Low x

Time: Travel 22 min. Beginning 10:24 Completion 10:37 Elapsed 13 min.

(Record all measurements in hundredths of a foot)

	Grasses							Weeds		Browse		
	Adi	Bcu	Ber	Bfi						Cer	Fsp	Kpa
	6	12	3	6						75	44	166
			3	4						110	191	45
			6	9						40	190	82
			4	3						35	183	80
			3	18						48		
			5	6						16		
			6	5						12		
			4	7						22		
			10	2						15		
			4	2						13		
				13						18		
				4						35		
				4						19		
				9						103		
				5						124		
				3						9		
				4						8		
										15		
Unit totals	6	12	48	104						717	608	373

Example 1.—Field record of a sampling unit showing recorded field measurements and compiled sampling unit (observation) totals. The spaces at the top of the form, for the notation of incidental information, are varied to suit the needs of the particular project.

Work Sheet

Block No.	Observation No.	Aba	Adi	Agl	Bch	Bcu	Ber	Bfi	Ein	Hbe	Hco	Ldu	Mpo	Mri	Tca	Total grasses Feet
		Grasses recorded in hundredths of a foot														
1	1		6			12	48	104								1.70
	2		39		5	26	66	32							77	2.45
2	3	13	44		34	164		19		26						3.00
	4		21				18				30		42		22	1.33
3	5		29			73	19	23			43				33	2.20
	6		32	2	172	7	10			135						3.58
4	7				35	86	8	16	8						4	1.57
	8		27		29	25		47			8					1.36
5	9		55		6		15				94				97	2.67
	10		9		87		48									1.44
6	11				50	7	15	39							14	1.25
	12	16			43	53	5					60		37	10	2.24
7	13	14	12		29	19	15									0.89
	14							6								0.06
8	15		14		61		68				6					1.49
	16				8			51			322					3.81
Totals		43	288	2	559	472	335	337	8	161	503	60	42	37	257	31.04
Sample means (feet)		.03	.18	T*	.35	.30	.21	.21	T	.10	.31	.04	.03	.02	.16	1.94

*"T" indicates a trace which cannot be expressed in percentage when significant figures are restricted to two decimal places.

Example 2.—Example of work sheet showing compilation of sample data and the computed means.

is actually occupied by grasses. All of these averages may be converted to percentages representing the relative amount of ground occupied. When a 100-foot sampling unit is used, the percentages of ground cover are read direct. One foot equals one-hundredth part of a 100-foot sampling unit, or 1 percent. Because of the sparseness of grass cover in the pasture from which our example was obtained, no individual species covers as much as 1 percent of the ground, hence the fractional percentages in every instance except the case of total grass cover which is 1.94 percent.

Percentages of ground cover cannot be read directly when a 50-foot sampling unit is used. The means obtained with a 50-foot sampling unit, however, may be converted to percentages by multiplying each mean value by 2. With a 25-foot sampling unit, the multiplier is 4, and for a 10-foot sampling unit it is 10. Obviously the same result may be obtained for sampling units of any length by multiplying the mean values by the reciprocal of the number of feet representing the length of the sampling unit.

Composition percent of a species is computed from the totals. For example, the composition percentage of Aba (Andropogon barbinodis) is 43 divided by 3,104. Thus:

$$\frac{43}{3,104} = 1.38531, \text{ which is recorded as } 1.38 \text{ percent.}$$

The composition percentages for all grasses, computed from the tables shown in example 2, are as follows:

Symbol	Scientific Name	Common Name	Percent Composition
Aba	Andropogon barbinodis	Silver beardgrass	1.38
Adi	Aristida divaricata	Poverty grass	9.28
Agl	Aristida glabrata	Smooth three-awn	0.07
Bch	Bouteloua chondrosioides	Sprucetop grama	18.01
Bcu	Bouteloua curtipendula	Side-oats grama	15.21
Ber	Bouteloua eriopoda	Black grama	10.79
Bfi	Bouteloua filiformis	Slender grama	10.86
Ein	Eragrostis intermedia	Lovegrass	0.26
Hbe	Hilaria belangeri	Curly-mesquite	5.19
Hco	Heteropogon contortus	Tanglehead	16.20
Ldu	Leptochloa dubia	Sprangletop	1.93
Mpo	Muhlenbergia porteri	Bush muhly	1.35
Mri	Muhlenbergia rigens	Deergrass	1.19
Tca	Trichachne californica	Arizona cottongrass	8.28
		Total	100.00

Totals and mean values for the densities and compositions of the weed and browse measurements are compiled and computed in exactly the same manner as is illustrated for the grasses.

In this manner the sample provides a detailed inventory expressed in percentages of the different grasses or other vegetation growing on the sampling area. Such information can be readily translated into acres of land completely occupied by any forage class or species. For example, this 1,000-acre pasture supports a grass cover of 1.94 percent (not to be confused with

reconnaissance density). Therefore, the total number of surface acres completely occupied by grasses is 1.94 percent of 1,000 or 19.4 solid acres of grass for the entire 1,000-acre pasture. A similar computation will provide an estimate of the total ground area occupied by any species for which the percentage of ground occupied has been derived. Such estimates of total stands expressed in standard units of area are not the same as the estimate of "forage acres" obtained by the usual range survey method.

Advantages of the line interception method in sampling ranges for density and composition of plant cover (forage plant inventory) are:

1. The estimates are based on measurements.

2. Measurements of individual classes of plants are made on randomly selected individual plants and at specified points of measurement on the plant where the error in measurement will be at the minimum.

3. Subjective influences are eliminated by random selection of sampling units.

4. The reliability or degree of precision of the sample means may be computed by standard mathematical formulae.

The Forage Utilization Survey

The essential difference between sampling utilization and sampling density and composition of the forage plant cover is that the sample of forage use includes, in addition to measurement of ground cover, a scheme for the classification of measured stubble heights which has been previously discussed.

The first step in the reduction of utilization survey sampling data is to compile the data recorded on the field sheets. This operation consists of a summation of field data by simple addition to obtain the sums of all measurements in each stubble-height class for each species concerned. The procedure necessary to accomplish this operation is indicated in example 3. Each individual sampling-unit field record sheet is handled in this way until the entire sample has been compiled.

When this first operation is completed for all sampling units, the second step is then undertaken. This step involves a separate compilation of all sampling-unit totals(obtained in step one, example 3) for each grass by height classes. For example, note that Adi is represented by six one-hundredths of stubble-height class 7 in sampling unit 1. This figure is transcribed on the work sheet shown in example 4 which illustrates the procedure to be followed in transcribing the field record totals for a particular species. This part of the job is completed when an individual work sheet of this kind has been prepared for each grass represented in the sample.

Example 5 is merely a compact tabular statement of the previously computed class totals. However, one new plant group has been introduced, namely, "Other" grasses. This group contains the sums of minor species, each of which provides less than 2 percent of the total grass cover. This 2-percent limit of significance is an arbitrary figure selected on the basis of the relative importance of minor species. A limit may be set up or not set up as the circumstances pertaining to the individual sample appear to warrant.

Utilization Survey Field Record

Project Range plant inventory | Sampling unit length 100 ft.

Block 1 Unit 1 Pasture No. A | Date 6-12-41

Location SW¼SW¼ sec. 27,T18S,R15E | Forage type 1 Examiners McK & J.S.

Topography hilltop Slope 0 | Fences 25 ch. SE. Water 3 ch. W.

Salt 1 mi. N. Roads 10 ch. Trails 1 ch. Rodent pop. High ___ Medium ___ Low x

Time: Travel 22 min. Beginning 10:24 Completion 10:37 Elapsed 13 min.

Grass species	Dead sod	Stubble-height classes recorded in hundredths of a foot: 0"-½" 1	½"+-1" 2	1"+-2" 3	2"+-4" 4	4"+-6" 5	6"+-8" 6	8"+-10" 7	10"+ 8	grazed 9	Height ungrazed grazed In.
Adi	0							6			
Total:	0							6			
Bcu	0		12								
Total:	0		12								
Ber										3-3 6-4 3-5 6-4 10-4	18-11 12-16 10-9 9-12 11-9
Total:										48	
Bfi	6-7 4	4-9 2-4 5	3-18 2							6-5 13-9 3-4	10-9 9-7 8-8
Total:	17	24	23							40	
Grand total: (feet)	0.17	0.24	0.35					0.06		0.88	

Example 3.—Showing the portion of the field record sheet that pertains to grasses. Note the manner of recording and the subsequent addition of field measurements of individual species to obtain the totals for each stubble-height class occurring within the species and, finally, the grand total for all grasses.

Utilization Survey Compilation Work Sheet

Species Adi

Block No.	Observation No.	Stubble-height classes in hundredths of a foot: 1	2	3	4	5	6	7	8	Ungrazed	Observation totals
1	1							6			6
	2			15		3		8		13	39
2	3		23	13						7	43
	4			9				7		5	21
3	5				17	10				2	29
	6		17							16	33
4	7										0
	8			10	6					11	27
5	9					10		15		30	55
	10						9				9
6	11										0
	12										0
7	13					7				5	12
	14										0
8	15			14							14
	16										0
Class totals			40	61	23	30	9	36		89	288

Example 4.—Example of work sheet showing the distribution of sampling-unit totals for grazed stubble by height classes for *Aristida divaricata* (Adi) as transcribed from field records of 16 sampling units.

Work Sheet

Species	Observed values, stubble-height classes, in hundredths of a foot								Ungrazed	Total grass
	1	2	3	4	5	6	7	8	9	
Adi		40	61	23	30	9	36		89	288
Bch	47	89	89	25					309	559
Bcu	13	73	69	20					297	472
Ber	14	10	15						296	335
Bfi	40	53	81	30					133	337
Hbe		85	59						17	161
Hco		15	31	41	10	9			397	503
Tca		29	21	39	11	31			126	257
Other	17	4	30	26	17				98	192
Totals	131	398	456	204	68	49	36		1,762	3,104

Example 5.—An example of a work sheet showing the compiled totals of the ground occupied by grass that has been grazed to the different stubble heights for each species within each stubble-height class.

The principal advantage in using a set limit for the grouping of relatively unimportant minor species is that it saves some time that would otherwise be expended in computing inconsequential percentages.

The final step in the compilation of a utilization sample is the conversion of all measured values transcribed on the work sheet (example 5) into percentages. Up to this point the sums of all measurements have been expressed in hundredths of a foot.

The first operation is the construction of a table after the manner of that shown in example 6. The name of each grass, or its assigned symbol, is then entered in the first column on the left. Percentages represented by each species are computed from the totals for each grass shown in the last column in example 5. The process is indicated in the previous discussion of percentage composition. For example, the total of Adi is 288 and the total of all grasses is 3,104. The percentage representing the relative amount of ground occupied by Adi is computed by dividing the total Adi (288) by the total grasses (3,104), i. e.,

$$\frac{288}{3,104} = 9.28 \text{ percent.}$$

This percentage figure is entered in the column set up for that purpose opposite the plant symbol Adi. The operation is continued for each species in turn until the totals for all species or groups such as "Other" grasses have been converted to percentages and entered in the "Percent Composition" column of a table such as that shown in example 6. Such an array of percentages shows the relative amount that each individual kind of grass contributes to the total forage cover.

In a similar manner the individual percentages for the distribution of stubble heights and the ungrazed complement within the species are computed for each grass. In this computation the total of a species is used as a base.

Utilization Survey Summary

Pasture No. A
Santa Rita Experimental Range

Date June 1941
Density 1.94%

Species	Percent composition	0-½" 1	½"-1" 2	1"-2" 3	2"-4" 4	4"-6" 5	6"-8" 6	8"-10" 7	10"+ 8	Percent ungrazed	Check sum
		Stubble-height classes in percent of species									
Adi	9.28		13.89	21.18	7.99	10.42	3.12	12.50		30.90	100.00
Bch	18.01	8.41	15.92	15.92	4.47					55.28	100.00
Bcu	15.21	2.75	15.47	14.62	4.24					62.92	100.00
Ber	10.79	4.18	2.98	4.48						88.36	100.00
Bfi	10.86	11.87	15.73	24.04	8.90					39.46	100.00
Hbe	5.19		52.80	36.64						10.56	100.00
Hco	16.20		2.98	6.16	8.15	1.99	1.79			78.93	100.00
Tca	8.28		11.28	8.17	15.18	4.28	12.06			49.03	100.00
Other	6.18	8.85	2.08	15.63	13.54	8.86				51.04	100.00
Mean use		4.22	12.82	14.69	6.57	2.19	1.58	1.16	0	56.77	100.00

Example 6.—Summarized statement of grazing use, in percentages.

For example, Adi has a total of 288 and the amount of this species in height class No. 2 is 40. Therefore:

$$\frac{40}{288} = 13.89\%,$$

representing the relative amount of this grass that has been grazed in class 2. All values for the amounts of each grass recorded under each stubble-height class are converted to percentages by a similar computation.

The mean use of all grasses occurring within the pasture is computed from the totals included in the bottom line of example 5. Again the total of all grasses (3,104) is used as the base in computing the average percentages of all grasses that have been grazed to the different heights and the average percentage of ungrazed grass cover.

The summary of a pasture survey that is presented in the utilization report is shown in example 6. A table of this kind contains a complete picture of the utilization of the range on which the survey was made. Each notation, each column, and each line tells a part of the utilization story. From the information contained in this summary the manner in which each grass is grazed can be compared with that of associated species, and the relative usability of each can be expressed in concrete terms. Furthermore, the amount of forage left unused at the time of the survey is measured. This last item may be regarded as the most vital factor in securing information relative to range management.

An additional advantage of the method is that mathematical tests may be applied to determine the degrees of reliability and precision of the information obtained from properly designed range samples. One of the best and most commonly applied mathematical tests is described in the following section.

Analysis of Data

In the foregoing examples of forage plant measurement the averages of a number of observations have been indicated as the numerical values representing the average conditions existing within the sampled area. Such averages are obtained by dividing the sum of all observations by the number of observations contained within the sample. Prior to comparatively recent times, an average was generally accepted at its face value, provided it did not conflict with preconceived opinion. Until the mathematician provided formulae that properly described the laws of probability in regard to averages based on small random samples, there existed no means by which the experimenter could test the reliability of his averages, although he often may have thought that there was a real difference between the values of averages. Now the reliability of a sample average or mean may be measured. Eminent mathematicians have provided us with a measuring stick which may be used in making estimates of the sampling error. When this error is known, we may determine the probability that our sample mean may be wrong by specified amounts. The unit of measurement is the standard error of the mean.

The standard error of a sample mean (or sampling error) is a measure of the variation that would be expected within a series of independent samples of the same size taken in exactly the same way from the same general source. The means of repeated samples are known to vary among themselves in a special way in which certain percentages of the means of succeeding samples are visualized as being dispersed at regular intervals on either side of the true mean. The standard error is a measure of the dispersion interval of a population of sample means. Our sample mean is our best available approximation of the true mean. The smaller the standard error in relation to the sample mean the greater the degree of confidence that may be placed in the sample, because the smaller the standard error the less likely it is that a new sample or series of new samples would provide a greatly different mean.

Calculation of the Standard Error of a Random Sample

Example 7 shows the manner in which the standard error is computed for the purely random sample. Note that the values in this example are taken from the column labeled "Total Grass" in example 2. In order to be able to present two comparable samples with which to demonstrate differences in sampling design, the block arrangement is ignored in the present calculation:

Step 1.—Prepare a work sheet similar to that shown in example 7; enter the sampling unit number in column 1.

Step 2.—Enter all observed values opposite the observation number in column 2 of the work sheet. For convenience in calculation, remove the decimal points. They can be replaced when needed.

Step 3.—Calculate the sample mean by obtaining the sum of all observations (1 to 16 in the example) and then dividing that sum by the number of observations. The result is:

$$\frac{3{,}104}{16} = 194 \text{ (the sample mean).}$$

Work Sheet

Total Grass (Random Sample)

Col. 1 Observation No.	Col. 2 Observed values	Col. 3 Deviations from mean	Col. 4 Deviations squared
1	170	-24	576
2	245	+51	2,601
3	300	+106	11,236
4	133	-61	3,721
5	220	+26	676
6	358	+164	26,896
7	157	-37	1,369
8	136	-58	3,364
9	267	+73	5,329
10	144	-50	2,500
11	125	-69	4,761
12	224	+30	900
13	89	-105	11,025
14	6	-188	35,344
15	149	-45	2,025
16	381	+187	34,969
Total	3,104	+637 -637	147,292
Mean	194		

Col. 5 — Calculation of sampling error

A. Symbols and essential terms:
- Number of observations (n) = 16
- Sample mean ($\bar{x}$) = 194 ft.
- Sum of squares (Ss) = 147,292

B. Standard deviation (s):

$$s = \sqrt{\frac{\text{Sum of squares}}{\text{Number of observations less 1}}}$$

(1) $= \sqrt{\frac{147,292}{16-1}} = \sqrt{\frac{147,292}{15}}$

(2) $= \sqrt{9819.47} = 99.093$

C. Standard error ($S\bar{x}$):

$$S\bar{x} = \frac{\text{The standard deviation}}{\text{Square root of number of observations}}$$

(1) $= \frac{99.093}{\sqrt{16}}$

(2) $= \frac{99.093}{4}$

(3) = 24.77325

(4) = 25 in rounded numbers

D. Convert all values to feet by moving the decimal two places to the left and write the mean and its standard error as: 1.94 ± 0.25.

Example 7.—Work sheet showing the manner in which the sample mean, the standard deviation of the sample, and the standard error of the sample mean are computed from a purely random sample of "n" observations.

Step 4.—Obtain the deviations from the sample mean for each individual observation, i. e., in "observation number 1" the deviation is 170-194=-24, a negative quantity and "observation number 2" by a similar calculation has a deviation of 245-194= +51, a positive quantity. Compute all deviation values in the manner indicated and enter them in column 3 of the work sheet. In so doing observe the positive and negative signs. Deviations for observed values greater than 194 will be plus. Deviations for values less than 194 will be minus. Check column 3 by adding algebraically the plus and minus quantities. The sum of the column of deviations added according to sign shall be zero (or nearly zero, depending on the extent of discrepancy that may be caused by rounding decimals). In this example, the sums are +637 and -637, equaling zero when added.

Step 5.—Square the individual deviations from the mean by multiplying each deviation by itself. The quality sign has no further significance since both plus and minus values when squared become positive numbers, i. e., according to the rules of algebra a plus times a plus is a positive value and a minus times a minus is also a positive value. Enter the squared deviations in column 4 of the work sheet.

Step 6.—Add all the values in column 4 to obtain the total sum of squared deviation. This sum is 147,292.

Step 7.—The calculations necessary to compute the standard error of a sample mean are presented in column 5 of the work sheet. The first operation, section A, is to organize and attach a mathematical symbol and name to each of the previously computed sums.

Step 8.—Details pertaining to the calculation of the standard deviation of a sample are illustrated in section B. To accomplish this operation divide the sum of squares (147,292) by the number of sampling units less 1; that is, 16-1=15. This division results in the quotient of 9,819.47. Extract the square root of 9,819.47 which is 99.093, the standard deviation of the sample. This term is a measure of the dispersion of individual sampling units.

Step 9.—Section B shows in detail the final operation in the procedure followed in deriving the standard error of the sample mean of a purely random sample. The operation involves the division of the previously computed standard deviation by the square root of the total number of observations. In the case at hand the standard deviation 99.093 is divided by the square root of 16, or 4, giving us a quotient of 24.77325 as the standard error of the sample mean.

Step 10.—The sample mean, as well as all observed values and their deviations, has been carried through the calculations in hundredths of feet. The operation is completed when the sample mean and its standard error is converted to standard units of measure. In our example this conversion is accomplished by moving the decimal point two places to the left. Thus 194 hundredths feet become 1.94 feet, and the standard error, 25 hundredths of a foot, becomes

0.25 foot. The mean and its standard error is always written in this form: 1.94±0.25.

Calculation of the Standard Error of a Representative Sample

Example 8 shows the manner in which the standard error of a representative sample is computed. In this compilation the values of sampling units within each of the blocks are given separate consideration. Each operation is demonstrated in example 8 and is described step by step as follows:

Step 1.—Prepare a work sheet with a lay-out similar to that shown in example 8. Label each column according to its proposed content and prepare to transcribe the essential values from the previously constructed work sheet similar to that shown in example 2.

Step 2.—Set down the block numbers in column 1, the sampling-unit numbers in column 2, and in column 3 enter each sampling unit's observed (total grass) value in its appropriate block and opposite its assigned sampling-unit number.

Step 3.—Add all the observed values in column 3. In the example the sum is 3,104. Thus, 170+245+300. . . .+187=3,104. Then divide 3,104 by the number of observations (16 in this case) to obtain the general mean, 194. This general mean is the now familiar sample mean but, in contrast to the mean of the purely random sample, it plays no further part in the calculation of the sampling error of the representative sample.

Step 4.—The next operation is to obtain the block averages (block means). To do this add the two observations contained within each individual block and divide the sum by 2. Enter the quotient in column 4 of the work sheet. For example, in block 1 the observations added are 170+245, giving a block total of 415. This sum divided by 2 is:

$$\frac{415}{2} = 207.5, \text{ the mean of block 1.}$$

Enter the block mean in column 4 of the work sheet. This operation is repeated for each individual block until the block means of all blocks contained in the sample have been calculated. At this point in the computation the essential differences between the methods of analyzing a representative sample and the previously analyzed random sample become apparent. The block averages obtained by dividing the sums of the block observations by the number of observations within the blocks are introduced and used to obtain the deviations in place of the previously used general mean. Instead of one general mean we now propose to use eight means, one for each block of the sample. These eight block means show how the forage cover of the range unit varies between the different blocks.

Work Sheet

Total Grass (Representative Sample)

Col. 1 Block No.	Col. 2 Obs. No.	Col. 3 Obs'd values	Col. 4 Block means	Col. 5 Deviations	Col. 6 Dev. squared
1	1	170	207.5	-37.5	1406.25
	2	245		+37.5	1406.25
2	1	300	216.5	+83.5	6972.25
	2	133		-83.5	6972.25
3	1	220	289.0	-69.0	4761.00
	2	358		+69.0	4761.00
4	1	157	146.5	+10.5	110.25
	2	136		-10.5	110.25
5	1	267	205.5	+61.5	3782.25
	2	144		-61.5	3782.25
6	1	125	174.5	-49.5	2450.25
	2	224		+49.5	2450.25
7	1	89	47.5	+41.5	1722.25
	2	6		-41.5	1722.25
8	1	149	265.0	-116.0	13456.00
	2	381		+116.0	13456.00
Total: 8	16	3104		+469.0 -469.0	69321.00
Mean		194			

Col. 7
Calculation of sampling error

A. Symbols and essential terms:

Total observations (N) = 16
Block (n) = 8
Sample mean ($\bar{x}$) = 194
Sum of squares (Ss) = 69321

B. Standard deviation (s):

s = The square root of: $\dfrac{\text{Sum of squares}}{\text{Number of observations minus number of blocks}}$

(1) $= \sqrt{\dfrac{69321}{16-8}}$

(2) $= \sqrt{\dfrac{69321}{8}}$

(3) $= \sqrt{8665.125}$

(4) $= 93.0866531$

C. Standard error ($S\bar{x}$):

$S\bar{x} = \dfrac{\text{Standard deviation}}{\text{Square root of total observations}}$

(1) $= \dfrac{93.0866531}{\sqrt{16}}$

(2) $= \dfrac{93.0866531}{4}$

(3) $= 23.27$

D. Converted to feet, the mean ± standard error equals: 1.94±.23.

Example 8.—Work sheet showing the manner in which the sample mean, the block means, the standard deviation of the sample, and the standard error (sampling error) of the sample mean is computed.

Step 5.—Obtain the deviation of each observation from its respective block mean. For example, the deviations from the block mean in block 1 are: 170-207.5=minus 37.5 and 245-207.5=plus 37.5. So long as we have only two observations per block the deviations have opposite signs but are numerically equals. Enter these plus and minus deviations from the block mean in column 5 of the work sheet. Repeat the operation for each individual block using the respective block mean in each case.

Step 6.—Square the deviations in column 5. Record the squared sums in column 6 of the work sheet. Add column 6 to obtain the total sum of squares. In our example 8 the sum of the squared deviations from the block means is 69,321.00.

Step 7.—At this point in the calculation the three values to be used in the computations of the standard deviation of the sample and the standard error (sampling error) of the sample mean are assembled. Refer to "A" in column 7 of the work sheet. The first value in this column is "Total number of observations designated by the symbol "N" and equalling 16. The second listed value is the number of blocks which is designated by the symbol "n" and in this case equals 8—the total number of blocks included within the sample. The third and last value is the sum of the squared deviations which is commonly referred to as the sum of squares and is designated by the symbol "Ss" and in this case equals 69,321.00 (the total of column 6).

Step 8.—The calculations necessary to obtain the standard deviation of a representative sample are shown in section B of column 7. In this operation the sum of squares is divided by the total number of observations less the number of blocks, i. e.,

$$\frac{69,321}{16-8} = 8,665.125.$$

Then the square root of the quotient 8,665.125 is extracted. The square root of 8,665.125 is 93.0866531. This root mean square is the standard deviation of the sample.

Step 9. Refer to column 7, section C. The standard error of the sample mean for a representative sample is calculated by extracting the square root of the total observation number—in this case 16 with a square root of 4—and then dividing the value previously obtained for the standard deviation by this square root, i. e.,

$$\frac{93.0866531}{4} = 23.27$$

Thus the standard error of the mean of the representative sample presented in example 8 is 23.27 and the sample mean may be written as 194$\pm$23.27.

Step 10.—Since the values are still in one-hundredths of feet, it is appropriate that the mean and its standard error should be converted to standard units of measurement. This conversion is accomplished by moving the decimal points two spaces to the left (dividing each

by 100). Now the sample mean is read 1.94$\pm$0.23 feet. It represents the average amount of grass growing on the average 100-foot sampling unit together with a plus or minus sampling error. The relative size of the standard error, when compared with the mean, is an index to the reliability of the sample mean.

You have noted that the same set of data were used in illustrating the procedure to be followed in the testing of the mean of the purely random sample and also in testing the mean of the representative sample. It will be observed that the difference between the standard errors computed by both methods is slight. This comparison brings into view a point that every field man should know; namely, that no legitimate trick of mathematics can add to or diminish the goodness of data after it leaves the field. As previously stated, the smaller the standard error compared to the mean the more reliable the sample is assumed to be. The use of the standard deviation and the standard error in measuring the degree of confidence that may properly be placed in a sample mean is explained in the following pages.

Reliability of the Sample Mean

Reliability of a sample mean (the reliability of the average) is an expression of the degree of confidence which may be placed in the assumption that the sample mean may represent the true mean of the parent population from which the sample was obtained. More precisely stated, the measure of reliability is the probable degree of fidelity with which the sample mean obtained from the sample in hand may be reproduced from the same source in repeated independent samples of the same size taken in exactly the same manner. Our sample is in this sense regarded as one member of a population of sample means for which we know the approximate standard error. The test for reliability is in effect a prediction of how <u>much</u> and under the laws of probability how <u>often</u> the averages of new samples of the same size would be likely to vary from the average of the one sample now under consideration.

The system of measurement used in evaluating the reliability of a sample mean is based on a curve constructed according to a mathematical formula which describes the normal frequency distribution of the different values of almost anything that can be counted or measured. It is called the "normal curve," the "normal law of error," and the "normal frequency distribution." All of which, generally speaking, are different names for one and the same thing, the theory being that the true mean or average is the center of the population and that the individuals that make up this population vary among themselves in a predictable manner in terms of their standard errors. For example, the variation within a population of means of samples of the same size taken from the same population of things is distributed in terms of the standard error. A scale which shows the normal frequency distribution of a population in percentages with reference to the deviations from the mean, expressed in terms of the mean of the sample at hand plus and minus one or more of its standard errors, is presented in figure 7. The central value on the scale is at zero. At this zero point there is no deviation (zero deviation) from the normal population mean. Note that plus and minus graduations are extended from the zero to the right and to the left. These plus and minus values of these graduations are multiples of the standard error which describe the distributional range of values above and below the known sample mean that will include stated percentages of sample means for all possible samples from a specific population of an identical size and manner of taking.

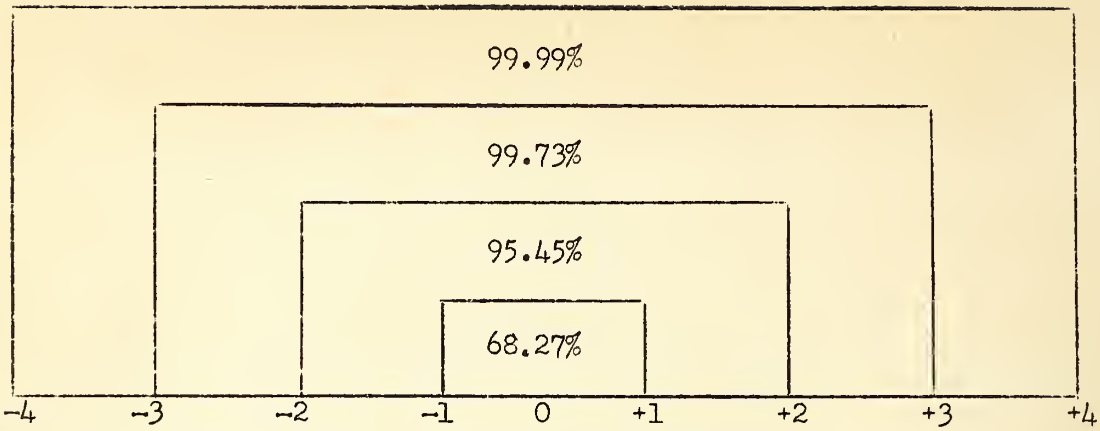


Figure 7.—Scale showing percentages of cases expected to be included within certain deviation brackets in the normal frequency distribution.

Thus, as shown in figure 7, we have the distribution of percentages to which we apply our computed standard errors in order to give exact numerical values to the intervals of deviation from our sample mean that normally contain stated percentages of the population from which the sample was obtained.

In order to demonstrate the use of our scale, suppose we apply our measuring stick to the sample presented in example 8. In this case our sample mean is 1.94 and the standard error (sampling error) is 0.23. If we visualize the scale placed with the mean of the sample at zero and the deviations plus and minus in multiples of this standard error (0.23), we shall be able to predict for repeated sampling the percentages of samples of this size that would be contained within the range of one or more standard errors. This measurement gives us a good estimate of how far the true mean of the population from which our sample was obtained may vary from the mean that we have calculated from the sample at hand. For example, we know the following to be true:

1. That a deviation from the mean as great or greater than one standard error in either direction will occur but once out of three trials. More precisely stated, 68.27 percent of the means of new samples of same size taken in the same way from the same population would be included between 1.94-0.23 and 1.94+0.23, or 1.71 and 2.17. We have on the average one chance out of three to get a sample with a mean that is as small or smaller than 1.71 and a similar probability of getting one that is as great or greater than 2.17.

2. In a similar manner a range of two standard errors on each side of the mean will contain 95.45 percent of the sample means. In this case we have one chance in 22 of getting a sample mean that is as small or smaller than 1.48 or as great or greater than 2.40.

3. Three standard errors on each side of the mean will contain 99.73 percent of the means of repeated samples. In this case we have one chance in 370 of getting a sample mean with a deviation from 1.94 as great or greater than 0.69 in either a plus or minus direction.

4. Four standard errors on each side of our mean may be expected to include practically all possible sample means of repeated samples. A range of six standard errors would leave only one chance in ten hundred million trials that a new mean having a plus or minus difference greater than this amount would be obtained. It is apparent then that the relative size of the standard error compared with its mean is a good yardstick when it is used to determine the reliability of a sample mean.

From the foregoing example it may be seen that it is possible to calculate the chances of being wrong by any stated number of standard errors. If the standard error is large, it may be reduced by increasing the sample size. It should be clearly understood that when the number of observations included within a sample are increased we have a new and different sample which should by reason of its greater scope, measured in terms of relative numbers of observations, afford a more exact estimate of the parent population mean. The new standard error thus obtained for the new and larger sample will describe the distribution of an entirely new population of sample means which may be obtained by repeated samples containing this greater number of observations. You have not changed the parent population or its true mean by this increase in sample size, although you should by reason of the greater scope of the sample and the resultant smaller standard error have a more precise estimate of it.

If the standard error is small, it is not unusual to have a condition in which any mean which might occur within a range of three standard errors of the sample mean would be an acceptable measure. If a range of three standard errors is allowable, the chances of repeating the sample within that range are very high. In our case (example 8) there is less than one chance in one hundred that repeated sampling would obtain a sample mean with a value smaller than 1.94 minus three standard errors (1.94-0.69=1.25) nor one with a sample mean value larger than 1.94 plus three standard errors (1.94+0.69=2.63).

The foregoing tests in example 8 show that the sample mean is sufficiently precise for many purposes. It is, however, one of the smallest samples taken in 1941, and it might be deemed advisable in certain types of work to increase the precision of our estimate of the sample mean. As previously stated, an increase in precision may be accomplished by taking a larger sample. The number of additional observations a new sample must contain in order to reduce the standard error to a desired size may be computed from the data of the sample at hand. Obviously a larger sample containing a greater number of observations is likely to provide a more accurate estimate of the parent population from which it is selected; therefore, the sample mean should have a relatively smaller standard error. This new standard error describes the dispersion of a new population of sample means obtained from larger samples and is not to be construed as a correction of the standard error of the smaller exploratory sample.

The Standard Deviation

Before proceeding further, the <u>standard deviation</u> should be explained. This term will prove useful in the succeeding calculations for determining the required size of a sample. The standard deviation is defined as the computed standard error of an observation (sampling unit) and describes the

dispersion of individual observations. For this purpose it is used in exactly the same manner as that described for the standard error of a sample mean. In this case, however, the object is to predict the chances of obtaining observations that are greater or smaller than the sample mean by specified amounts.

When the probabilities of obtaining sampling units with extremely large values or extremely small values which tend to produce a larger deviation from the mean and which in turn result in large standard deviations are known, we can proceed to calculate the size of sample required to assure us that these infrequent large and small values shall occur in the sample only in their proper proportion.

Calculations Necessary To Determine Number of Observations Required

As previously stated, the reliability of a sample mean is inversely proportional to the magnitude of the error of sampling. The smaller the relative size of the standard error is to the sample mean the greater the degree of confidence one may place in the sample. The precision of the sample mean is increased as the size of its standard error is diminished. As a general rule the standard error of a random sample mean will be halved when the number of observations is increased four times. This rule-of-thumb is better than a guess. However, when the mean and its standard error are known for an exploratory sample containing a given number of observations, the calculation of the approximate number of additional observations required to reduce the sampling error to any desired size is a relatively simple operation.

In example 8 the mean and its standard error is 1.94 ± 0.23. This standard error may be considered as being fairly large for certain experimental purposes. Suppose it is planned to go out in the field and secure enough additional samples to reduce the percent mean sampling error to a level of 10 percent or less of the sample mean. As the situation stands now, the sample comprised of 16 observations has a sample mean of 1.94 and a standard error of 0.23, or a sampling error of 11.8 percent of the sample mean. In order to calculate the number of additional sampling units required to secure the more acceptable sampling error, which we may set at 10 percent of our present sample mean of 1.94, or 0.194, we should proceed in the manner hereinafter described.

With odds of 22 to 1 against the occurrence of larger than the specified error, the calculations are as follows:

<u>Step 1</u>.—Square the standard deviation of the sample at hand (see example 8). The standard deviation 0.93 squared equals 0.8649.

<u>Step 2</u>.—Square the maximum allowable standard error. Our proposed standard error 0.194 squared is 0.037636.

<u>Step 3</u>.—Divide the squared standard deviation by the squared maximum allowable standard error, i. e., 0.8649 divided by 0.37636 equals 22.98. This quotient rounded to a whole number is 23, representing the number of sampling units necessary to secure a mean with a sampling error of 10 percent or less with a chance that this error will be equalled or exceeded once in 22 trials. We have 16 sampling units; therefore, 7 more sampling units are required.

If greater precision is desired, for example odds of 370 to 1 (a range of $\pm$ three standard deviations) against larger than the 10-percent specified error, the following calculations are made:

Step 1.—Square the standard deviation as before.

Step 2.—Multiply the square standard deviation by 3 squared (3x3=9) then 9x0.8649=7.7841.

Step 3.—Divide 7.7841 by the square of a desired standard error, i. e.,

$$\frac{7.7841}{0.037636} = 206.8$$

The foregoing calculations indicate that on the average a series of samples comprised of 207 (206.8 rounded) sampling units each would provide a sample mean with a sampling error of 10 percent or less in 99.73 percent of the cases, or odds of 370 to 1 against obtaining errors equal to or greater than the specified 10 percent of the sample mean.

Possible Extensions in Use of the Method

The line interception method has two highly adaptable properties, namely, actual measurement of the thing observed and the ease with which the method can be applied in sampling vegetation. Potentially, the method may be used wherever any kind of measurement can be made. The sample may consist of determinations of volume, weight, height, length or area, or any other attribute that is expressible through any of our standard systems of measurement. Plant density, composition, and degree of forage use do not describe the limits of its usability. For example, the method has produced highly satisfactory results in limited trials wherein small samples of grasses were clipped and weighed to obtain an estimate of forage volume. The procedure followed was to clip and weigh the grasses growing on a narrow belt transect thereby obtaining a measure of forage volume per unit of area. A measurement of plant density and composition was obtained by measuring the ground occupied by plants on a line which bisected the full length of the belt. A sample obtained in this manner contains the usual measurements of forage composition, density, and also a measure of forage volume per unit of ground area. Such samples show that there is a high correlation between density of ground occupied by the plants and the volume of forage produced. When small sampling units not to exceed one ten-thousandth of an acre in area are clipped, the work of sampling is not a tedious job.

Another possibility of extending the usefulness of the line interception method is presented in adapting it to range surveys. With the present system of aerial mapping available there appears to be no reason why range forage types should not be sampled in a manner similar to that herein described for sampling range allotments or pastures.

Suggested Reading

If the practical man desires to read further concerning the theory of sampling, the following references are recommended:

(1) Gerard, James W., and Gevorkiantz, Suren R.

Timber cruising. U. S. Forest Service, 1939.

(2) Schumacher, F. X. and Chapman, R. A.

Sampling methods in forestry and range management. Duke University Bull. No. 7, 1942. (A clear presentation of sampling methods well illustrated by examples.)

(3) Snedecor, George W.

Statistical methods. Ed. 3, 1940. Iowa State College Press, Ames, Ia. (Up-to-date, practical, and easy to read.)

RESEARCH REPORT

SOUTHWESTERN FOREST AND RANGE EXPERIMENT STATION[1]
Raymond Price, Director

Report No. 5 January 1943

GROWTH AND MORTALITY IN A VIRGIN STAND OF PONDEROSA PINE COMPARED WITH A CUT-OVER STAND

by

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1/Maintained by the Forest Service, U. S. Department of Agriculture, for Arizona, New Mexico, and west Texas, with headquarters at Tucson, Arizona.

2/The data were collected and compiled by the senior author while employed at the Southwestern Forest and Range Experiment Station.

GROWTH AND MORTALITY IN A VIRGIN STAND OF PONDEROSA PINE COMPARED WITH A CUT-OVER STAND

The immediate silvicultural task in the management of ponderosa pine for saw timber in the Southwest is the conversion of overmature virgin stands into well balanced young stands of rapid growth and high quality. This process is necessarily a slow one, involving as it does not only removal of old and undesirable trees but also their replacement by a younger generation. Moreover, substantial areas of old timber will remain uncut for another 20 years. It is possible, however, to take some of the initial steps of conversion far in advance of actual logging. Most important of these is the restocking and training of pole stands in open spaces which in some virgin forests occupy as much as 50 percent of the area.

With the object of ascertaining what changes actually take place in a natural forest under protection, a sample plot of 120 acres was established 27 years ago in what is now the Fort Valley Experimental Forest. Ten years later the area was enlarged to 160 acres, and all the trees were numbered for individual record. At the same time an adjoining newly logged area of 160 acres was also made into a sample plot and the two plots have since been carried in parallel records. Although reference is made, for certain purposes, to the older virgin stand records, this report concerns primarily the two sets of records begun in 1925.

Site and Stand Description

Site

Both plots are located within 1 mile of the Fort Valley headquarters, 9 miles northwest of Flagstaff, Ariz. The elevation is between 7,400 and 7,500 feet above sea level and the topography is gently rolling. The soil is a clay loam resulting from the disintegration of basalt. Annual precipitation averages slightly more than 23 inches. The plots are located on what is considered site 2 for ponderosa pine in the Southwest. Virgin stands on this site bear up to 20,000 board feet per acre and mature dominants attain heights of 120 to 130 feet. The site corresponds to quality IV in California and eastern Oregon.

Composition

Prior to 1924 the two stands were comparable as to merchantable volume and tree size, both containing between 11,000 and 12,000 board feet per acre. Most of the trees were in three broad age classes: yellow pines, mainly over 200 years old and making up the bulk of the volume; blackjacks and intermediates, 100 to 200 years old; a few poles under 100 years old; and a large number of seedlings mainly of 1919 origin. The cut-over plot was logged under Forest Service administration in 1924. Cutting was by the group selection system, removing about 8,000 board feet per acre, largely from the yellow pine component of the stand, and leaving 3,400 board feet.

Plot Measurements

All trees 3.6 inches d.b.h. and larger were tagged and their diameters were recorded in 1925. Both plots have since been remeasured at 5-year intervals. At each remeasurement the "new trees" (those entering the 4-inch d.b.h. class) were tagged, and those which died were noted, with the cause of death. Many other changes, difficult to measure but detected by observation, were also noted. Most important of these was natural restocking which was practically nil prior to 1913, became complete in 1919, and was reduced somewhat on the logged area in 1924.

Changes in Stand Structure

Tables 1 and 2 show number of trees and volume per acre on the two plots at the beginning and end of the 15-year period. A stand table of the cut-over area before logging is not available, but reconstruction of the stand with the aid of sale records indicates that the volumes on the two areas were nearly equal. In 1925 the total number of trees per acre is seen to be but slightly less in the cut-over than in the virgin stand. Cutting noticeably lowered the number of trees 18 inches d.b.h. and over, but as it happens the cut-over area originally had a larger number of trees below 18 inches, which almost offsets the loss in higher diameter classes.

Changes in distribution of diameter classes have been slight in the virgin stand but very pronounced in the cut-over stand. In the cut-over stand a definite stepping up of diameter classes is easily seen; many of the trees in each diameter class grew about 3 inches in diameter during the 15 years. As a result the entire column of figures under "No. trees" has, with minor changes, moved down one line in the 1940 tabulation. In addition, numerous smaller trees have entered the 9- to 12-inch class from below, bringing the total number of trees now above 8 inches in the cut-over stand to more than that in the virgin stand.

Diameter Growth

Table 3 shows the diameter growth and number of trees by d.b.h. classes in the two stands. This table brings out a striking advantage of the cut-over plot in number of trees in the lower diameter classes. Although the comparison is made 10 years after the cutting, the difference in number of small trees cannot be attributed to cutting because for diameter classes below 11 inches the growth rate after cutting is almost identical on the two areas; at 11 inches, however, growth in the cut-over stand begins to forge ahead and it maintains a definite lead to the top of the series of diameter classes.

Gross Increment

Table 4 shows the gross increment by 5-year periods. It declines noticeably in the virgin stand but only slightly in the cut-over. Only during the first period was the gross increment in board feet much higher in the virgin than in the cut-over stand. The obvious deduction is that volume of growing stock *per se* does not govern the rate of increment. A rise of increment accompanies a rise in volume of growing stock only if this means more complete utilization of the soil, especially where new trees take possession of soil space hitherto unused.

Percent of volume increment is naturally influenced by the volume base, or the principal from which the rate of increment is derived. Since the volume at the beginning of the record was three times as high in the virgin as in the cut-over stand, growth in the former would have to be three times as high in order to keep pace with the cut-over stand. Since actual gross increment was but little higher in the virgin stand, the percentage rate is roughly one-third of that in the cut-over stand.

The increment percent declined over the 15-year period because the volume base was continually rising. This was true of both plots but more so on the cut-over because net increment was higher. On this plot the volume increased by nearly 500 board feet in each 5-year period.

Mortality

Trends

Relative mortality in the two stands is shown in table 5. Obviously the cutting lowered mortality by removing trees which were in an advanced state of decline. The volume lost in the cut-over stand during the three periods has remained almost stationary; in the virgin stand, however, there was a sharp rise during the last 5-year period. Fluctuation of mortality in the virgin stand is to be expected because of the large number of highly susceptible trees. Abnormal intensity of any adverse condition such as drought, wind, or lightning may kill many of the veterans. The elimination of highly vulnerable trees during such a period tends to raise the general level of resistance, resulting in a compensating decline of mortality during the period immediately following.

Although three periods are not sufficient to establish a trend, it should be recognized that forces are at work which inevitably bring about increasing losses in both numbers and volume. As the mature components of a stand grow older and larger they become more susceptible to wind and lightning. In a previous article[3] it has been shown that only one-third of the trees which are struck by lightning die immediately or even within several years; some recover but others decline and die later. Mistletoe is an insidious enemy which works slowly but with deadly effect. In groups which have not been adequately opened up, root competition, in conjunction with drought and bark beetles, takes an increasing toll. In the course of 20 to 30 years all of these agencies working toward a common end may be expected to exert a cumulative influence in both virgin and cut-over stands. Three large cut-over sample plots on record during 25 to 30 years show some tendency toward fluctuation but also point unmistakably toward a gradually rising mortality rate.

Fluctuation rather than a continuous trend is likely to characterize virgin stands. This is indicated by a 25-year record on the original 120 acres of the uncut sample plot previously mentioned. Annual mortality by 5-year periods from 1915 to 1940, expressed in board feet per acre, was: 41, 107, 50, 40, 112. (See also table 13.)

3/ Wadsworth, Frank H. Lightning damage in ponderosa pine stands of northern Arizona. 1942. (Submitted to Jour. Forestry.)

Relation to Tree Diameter

Mortality by broad diameter classes in the two plots is shown in tables 6 and 7. In both virgin and cut-over stands the loss in the upper diameter classes is conspicuously greater than in the lower classes. Other sample plots in the Fort Valley Experimental Forest have borne out this relationship.[4] The cut-over stand with almost one-third the 1925 volume of the virgin stand suffered only one-fifth the volume loss of the latter. On a percentage basis the contrast is less striking because of the larger volume base in the virgin stand. The tables also suggest that removal of most of the trees above 20 inches d.b.h. on the cut-over plot precluded the high mortality commonly found in the larger sizes, particularly in the "31-inch plus" class, in the virgin plot, without a compensating increase of mortality in the trees of smaller diameters.

Relation to Age Classes

In tables 8 and 9 the mortality on the two plots is shown by blackjack and yellow pine separately. The higher mortality in the older age class is marked. In the cut-over plot more blackjacks and fewer yellow pines were killed than in the virgin plot. Removal of most of the yellow pines by cutting left few of them to be killed and at the same time exposed the blackjacks to wind and lightning, the two most important causes of mortality.

Because the yellow pines are generally larger than the blackjacks the difference between losses in the two stands is greater when expressed in volume than in number of trees. The ratio of loss in the virgin plot to that in the cut-over plot is 2 to 1 for number of trees and 5 to 1 for volume.

When measured in percent of either numbers or volume, blackjack mortality is much lower than yellow pine mortality in both plots. As has been pointed out, yellow pines, being taller, are more likely to be struck by lightning than are blackjacks; also, after being struck, yellow pines are more likely to die. Windfall is also more prevalent among yellow pines.

Although the mortality percent of both blackjack and yellow pine alone is higher for the cut-over than for the virgin stand, the relation is reversed when blackjack and yellow pine classes are combined. The explanation of these apparent contradictions is to be found in differences in the actual numbers of trees on which percentages are based.

Causes

Tables 10 and 11 show lightning to be the chief cause of mortality in both plots. Because lightning usually strikes the tallest and largest trees in the stand it is responsible for the loss of considerable merchantable volume. In the virgin plot 42.8 percent of the volume-loss, or 384 board feet per acre, during the 15 years of record

[4] Pearson, G. A. Mortality in cut-over stands of ponderosa pine. Jour. Forestry 37:383-387. 1939.

is attributed to lightning. In the cut-over plot the corresponding figures are 50.0 percent and 90 board feet per acre. Annual lightning losses per acre were 25.6 board feet in the virgin stand and 6 board feet in the cut-over. When it is considered that only one-third of the trees struck die at once but that nearly all deteriorate, the importance of lightning becomes more significant.

Bark beetles were responsible for a large share of the volume loss, particularly in the virgin stand where this agency ranked second among causes of death. Many of the trees were recorded as killed by a combination of either lightning and insects or mistletoe and insects. Because the most common injurious forest insects in this locality (Ips sp. and Dendroctonus valens) are usually secondary in the overstory, the associated cause is considered the primary one in this analysis. In the absence of other visible cause, the death of trees which show signs of severe beetle attack is attributed directly to the beetles. Bark beetles caused 27.3 percent of the total 15-year loss of 907 board feet per acre in the virgin plot, or 16.5 board feet per acre annually. In the cut-over plot the corresponding figures were 11.5 percent of 175 board feet or 1.3 board feet per acre annually.

Wind mortality ranks second on the cut-over and third on the virgin plot. Nearly all of the windfall occurred during the last period and contributed materially to the sharp rise in total mortality of the virgin plot. Windfall accounted for 18.2 percent of the volume loss in the virgin stand, or 11 board feet per acre annually during the 15 years. In the cut-over stand the corresponding figures were 23.2 percent and 2.7 board feet per acre annually.

Mistletoe is seen to be of little importance as a cause of mortality in these plots. Practically all the trees killed by mistletoe were small and as a result the volume loss has not been great. The local variation in the severity of mistletoe is seen in that only 3.8 percent of the volume loss in 15 years is attributed to mistletoe in the cut-over plot, as compared with 37.6 percent during 30 years in the similar cut-over Wing Mountain plot, 4 miles distant.[5]

Net Increment

As shown in table 12, net increment of the virgin stand (gross increment less mortality) was consistently much below that of the cut-over stand, both in board feet and in percent. Particularly was this true in the last period when heavy windfall lowered the net increment to 3 board feet per acre per year, or 0.02 percent of the volume. The fact that mortality on the cut-over area during this final period increased only 1 board foot per acre is a tribute to silviculture. During 15 years the cut-over area has increased in volume at an average annual rate of 96 board feet per acre as compared with 48 for the uncut area.

[5] Pearson, G. A., and Wadsworth, Frank H. An example of timber management in the Southwest. Jour. Forestry 39:434-452. 1941.

Other cut-over sample plots in the Fort Valley Experimental Forest have experienced a sharp and sustained decline of increment, both gross and net, after the second 5-year period; but in this instance the cut-over plot has shown no indications of a decline during the third period. Whether and how long the even course of the past 15 years will continue is a subject worthy of observation. There are two factors which may have the effect of postponing a decline. One is a modification of the usual cutting practice in group selection whereby groups of large blackjacks and intermediates were opened up considerably. Another factor is the low incidence of mistletoe on this plot.

Further Analysis of the Virgin Stand

A better view of changes and trends in the virgin stand is obtained from a 25-year record of the original virgin plot. During the first 10 years, as has been stated, the trees were not tagged and therefore a detailed analysis is not possible for this period; but for mass measurement of increment and mortality the record is adequate. Table 13 gives increment and mortality by 5-year periods from 1915 through 1940.

The first two periods register the highest gross increment and the second highest mortality of the entire series. A gross annual production of 139 board feet from 1920 to 1925 is suggestive of possibilities with mortality under control. A net annual increment of 83 board feet per acre is attained in the first period; in the third and fourth it was 66, but in the fifth mortality exceeded growth by 10 board feet. The picture as a whole is one of erratic fluctuation, which is to be expected. A stand whose volume is made up largely of mature and overmature trees would be extremely sensitive to unusual weather conditions such as a combination of high winds and waterlogged soil. A succession of dry summers might accomplish the same thing because in dense groups of old trees the reserve of soil moisture must inevitably be low. Because large, slow-growing trees are especially subject to bark beetles, it is suggested that root competition may be an important factor in insect losses.

Acceleration of growth in surviving trees might be expected to follow high mortality, but for the fact that the number eliminated is seldom sufficient to relieve competition. In individual cases, however, the remaining trees are benefited. Probably the greatest effect of mortality is to liberate the younger generation.

The common assumption that virgin stands remain stationary because growth is offset by mortality is not borne out by these records. Despite two periods of extreme mortality, the mean annual net increment during 25 years has been 47 board feet per acre. If a much larger proportion of the stand were mature, mortality might balance growth. It should be borne in mind, however, that maturity, as exemplified by the yellow pine class normally below 300 years old, does not preclude substantial growth. Yellow pines 250 years old in a group may be stagnant, but they respond to release when several members of the group are removed.

More than half of the soil is normally occupied by immature classes. A detailed map of an adjoining 80-acre tract in 1940[6] showed that only about 25 percent of the entire area was occupied by the yellow pine class, even though a border strip of 25 to 50 feet surrounding each group and extending out into thrifty reproduction was assigned to each yellow pine group. Blackjacks and intermediates occupied another 25 percent, and poles, saplings, and seedlings accounted for nearly all of the remaining space.

Blackjacks as a class make substantial diameter growth even in virgin stands. Besides, in the stand here recorded an appreciable number of poles have entered the 12-inch diameter class each 5-year period. As time goes on, this movement is going to assume large proportions because about half the total ground space is occupied by reproduction of 1919 and 1913 origin. In 1935 the trees 4 to 11 inches d.b.h. numbered 16 per acre.

Virgin stands vary greatly in density and distribution of age classes, but it can be said that rarely are mature elements utilizing more than 30 percent of the soil on areas as large as 40 acres. Where reproduction has been successful, advance of the young generation is going to alter the whole aspect of these stands. Also, in time the young trees are going to enter into sharp competition for moisture. The persistent decline of gross increment on this area since 1925 (table 13) could be attributed in part to a gradual invasion by saplings of the root zone of older trees which are known to feed far beyond the area outlined by their crown projections. It is possible to picture a temporary situation in which competition by poles and saplings may slow down the growth of the older trees without compensating for the loss in board-foot increment. But eventually, as the younger generation attains board-foot size, the increment of the stand as a whole should rise above the level existing before competition between the classes began.

Summary

1. In this investigation a virgin stand of ponderosa pine has been compared with a cut-over stand of the same species. Conclusions are drawn from measurements of diameter and records of mortality at 5-year intervals over a period of 15 years. A supplementary record of volume increment and mortality in a portion of the virgin stand is available for 25 years.

2. Virgin stands of ponderosa pine in the Southwest are capable of substantial increment because, as a rule, the greater portion of the area within such stands is occupied by immature age classes or may be practically vacant. Under protection the volume increases and the growing stock builds up in the lower diameter classes.

6/Pearson, G. A. Improvement selection cutting in ponderosa pine. 1942. Jour. Forestry 40:753-760.

3. Net increment is greatly influenced by mortality, which during short periods may equal or exceed gross increment. During 25 years the mean annual net increment on an area of 120 acres was 47 board feet per acre. Mortality fluctuated greatly when broken down into 5-year periods.

4. Removal of 70 percent of the volume under a modified form of the group selection method which opened groups of large blackjack resulted in marked stimulation of diameter growth. In the virgin stand diameter growth fell off rapidly above the 10-inch class. In the cut-over stand growth was well sustained through the 24-inch class and remained as high as 1 inch per decade in the few large trees measuring up to 37 inches d.b.h.

5. Cutting under the group selection method as here practiced has proven effective in lowering mortality. Whether lighter cutting can be made to accomplish nearly the same reduction of mortality while increasing gross increment is a subject deserving further investigation.

6. The relative order of magnitude of the toll taken by the several killing agents, expressed in percent of number of trees or volume of the stand in 1925, is as follows:

Virgin stand: lightning, bark beetles, wind, mistletoe.

Cut-over stand: lightning, wind, bark beetles, mistletoe.

7. Mistletoe ranks lower on both of these areas than on most of the sample plots in the Fort Valley Experimental Forest, and it is probably much below the average for the Coconino Plateau.

8. As on all sample plots in the Fort Valley Experimental Forest, the greatest volume loss occurs in the higher diameter classes and it is much higher for yellow pine than for blackjack.

Table 1.- Number of trees and volume per acre in the virgin stand, Sample Plot S6, 160 acres.

D. b. h. class	1925		1940	
	Trees	Volume	Trees	Volume
Inches	No.	Ft.b.m.	No.	Ft.b.m.
9-11	2.33		3.83	
12-14	2.36	143	2.85	171
15-17	2.83	375	2.51	330
18-20	3.31	833	3.28	838
21-23	3.35	1,435	3.45	1,496
24-26	2.83	2,097	2.93	2,190
27-29	2.02	2,132	2.24	2,347
30-32	1.46	2,000	1.57	2,145
33-35	0.72	1,260	0.77	1,360
36-38	0.34	766	0.37	805
39-41	0.19	505	0.19	523
42-44	0.06	181	0.08	246
45-47	0.01	24	0.01	24
48-50	0.01	27	0.01	29
Total	21.82	11,778	24.09	12,504

Table 2.- Number of trees and volume per acre in the cut-over stand, Sample Plot S7, 160 acres.

D. b. h. class	1925		1940	
	Trees	Volume	Trees	Volume
Inches	No.	Ft.b.m.	No.	Ft.b.m.
9-11	5.93		11.93	
12-14	4.18	219	5.97	300
15-17	3.73	472	4.17	542
18-20	2.61	653	3.21	780
21-23	1.76	733	2.41	1,001
24-26	0.86	558	1.53	984
27-29	0.46	425	0.65	612
30-32	0.16	196	0.31	404
33-35	0.04	62	0.08	124
36-38	0.02	67	0.02	38
39-41			0.02	47
Total	19.75	3,385	30.30	4,832

Table 3.- Diameter growth of ponderosa pine in a virgin stand compared with a cut-over stand. Sample plots S6 and S7, Fort Valley Experimental Forest, 1925 to 1935. Area of each plot, 160 acres.

D. b. h. class	Trees in class		Diameter growth1/ 1925-1935	
	Virgin	Cut-over 1935	Virgin	Cut-over
Inches	Number	Number	Inches	Inches
4	298	1,270	2.01	1.75
5	307	1,126	1.82	1.72
6	242	841	1.61	1.77
7	228	721	1.71	1.78
8	165	547	1.78	1.80
9	154	421	1.78	1.75
10	100	317	1.74	1.60
11	113	258	1.44	1.54
12	121	263	1.13	1.53
13	122	206	1.03	1.61
14	133	212	.89	1.62
15	131	233	1.00	1.61
16	147	203	.97	1.59
17	169	163	1.01	1.53
18	185	138	.99	1.59
19	171	135	.87	1.64
20	166	144	.90	1.62
21	210	95	.90	1.40
22	149	98	.86	1.44
23	166	80	.76	1.43
24	172	55	.85	1.38
25	143	41	.73	1.33
26	128	39	.68	1.34
27	98	31	.71	1.21
28	112	26	.60	1.22
29	103	10	.57	1.10
30	84	16	.54	1.35
31	70	7	.54	1.06
32	66	3	.53	1.20
33	46	4	.50	1.13
34	36	1	.53	1.70
35	26	1	.54	.90
36	20	1	.45	1.20
37	18	3	.50	1.66
38	13	0	.23	
39	16		.31	
40	7		.43	
41	7		.57	
42	4		.50	
43	3		.33	
44	1		-	
46	1		-	
48	1		1.00	

1/Not curved.

Table 4.- Periodic annual gross increment per acre and in percent of volume[1] in virgin and cut-over stands.

Forest	1925 to 1930		1930 to 1935		1935 to 1940	
	Ft.b.m.	Percent	Ft.b.m.	Percent	Ft.b.m.	Percent
Virgin	121	1.03	111	0.91	105	0.84
Cut-over	108	3.19	109	2.81	110	2.52

1/Percent of total volume at the beginning of each 5-year period.

Table 5.- Periodic annual mortality per acre and in percent of volume[1] in virgin and cut-over stands.

Forest	1925 to 1930		1930 to 1935		-1935 to 1940	
	Ft.b.m.	Percent	Ft.b.m.	Percent	Ft.b.m.	Percent
Virgin	45	0.38	44	0.36	102	0.82
Cut-over	10	0.29	13	0.33	14	0.32

1/Percent of total volume at the beginning of each 5-year period.

Table 6.- Mortality in relation to tree diameter in virgin stand, Sample Plot S6, 160 acres. 1925-1940.

D.b.h. class	1925 Stand				Mortality			
	Total		Per acre		Total 15 years		Annual percent[1]	
	Trees	Volume b.m.	Trees	Volume b.m.	Trees	Volume b.m.	No. Trees	Volume b.m.
Inches	No.	Ft.	No.	Ft.	No.	Ft.	Pct.	Pct.
12-20	1,361	216,190	8.51	1,352	34	5,950	0.17	0.18
21-30	1,402	1,017,290	8.76	6,358	73	58,350	0.35	0.38
31+	356	650,920	2.22	4,068	46	80,820	0.86	0.83
12+	3,119	1,884,400	19.49	11,778	153	145,120	0.33	0.51

1/Percent of 1925 stand.

Table 7.- Mortality in relation to tree diameter in cut-over stand, Sample Plot S7, 160 acres. 1925-1940.

D.b.h. class	1925 Stand				Mortality			
	Total		Per acre		Total 15 years		Annual percent[1]	
	Trees	Volume b.m.	Trees	Volume b.m.	Trees	Volume b.m.	No. Trees	Volume b.m.
Inches	No.	Ft.	No.	Ft.	No.	Ft.	Pct.	Pct.
12-20	1,683	215,100	10.51	1,344	30	4,420	0.12	0.14
21-30	508	292,430	3.17	1,828	33	21,520	0.43	0.49
31+	21	34,130	0.13	213	1	2,280	0.32	0.44
12+	2,212	541,660	13.81	3,385	64	28,220	0.19	0.35

1/Percent of 1925 stand.

Table 8.- Mortality in the virgin ponderosa pine stand, blackjack and yellow pine separate. 1925 to 1940.

1925 D.b.h. class	Number of trees lost, per acre and percent[1/]						Volume lost, board feet, per acre and percent[1/]					
	Blackjack		Yellow pine		Total		Blackjack		Yellow pine		Total	
Inches	No	Pct.	No.	Pct.	No.	Pct.	Ft.	Pct.	Ft.	Pct.	Ft.	Pct.
12-20	0.09	1.39	0.12	5.94	0.21	2.47	14	1.46	23	5.96	37	2.74
21-30	0.04	1.50	0.42	6.90	0.46	5.25	19	1.29	346	7.08	365	5.74
31+	-		0.28	12.78	0.28	12.61			505	12.54	505	12.41
12+	0.13	1.41	0.82	7.96	0.95	4.87	33	1.33	874	9.40	907	7.70

1/Percent of 1925 stand.

Table 9.- Mortality in the cut-over ponderosa pine stand, blackjack and yellow pine separate. 1925 to 1940.

1925 D.b.h. class	Number of trees lost, per acre and percent[1/]						Volume lost, board feet, per acre and percent[1/]					
	Blackjack		Yellow pine		Total		Blackjack		Yellow pine		Total	
Inches	No.	Pct.	No.	Pct.	No.	Pct.	Ft.	Pct.	Ft.	Pct.	Ft.	Pct.
12-20	0.15	1.34	0.03	6.52	0.18	1.71	22	1.74	5	6.17	27	2.01
21-30	0.10	4.52	0.11	11.46	0.21	6.62	44	3.73	90	13.89	134	7.33
31 +	0.00	0.00	0.01	8.33	0.01	7.69	0	0.00	14	7.11	14	6.57
12 +	0.25	2.04	0.15	9.74	0.40	2.90	66	2.68	109	11.77	175	5.17

1/Percent of 1925 stand.

Table 10.- Fifteen-year mortality in the virgin stand, by causes.
Percent1/ of number and volume b.m. killed by different agencies, 1925-1940.
Sample Plot S6, 160 acres.

D.b.h. class	Lightning		Wind		Bark beetles		Mistletoe		Unclassified		Total	
	No. trees	Volume b.m.	No. trees	Volume b.m.	No. trees	Volume b.m.	No. trees	Volume b.m.	No. trees	Volume b.m.	No. trees	Volume b.m.
Inches	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
12-20	0.4	0.4	0.5	0.6	0.8	0.8	0.3	0.3	0.5	0.6	2.5	2.7
21-30	1.4	1.9	1.4	1.3	2.0	2.0	0.1	0.1	0.3	0.4	5.2	5.7
31 +	6.3	6.4	1.8	1.7	2.7	2.7	0.4	0.3	1.4	1.3	12.6	12.4
12 +	1.5	3.3	1.0	1.4	1.6	2.1	0.3	0.2	0.5	0.7	4.9	7.7
Percent of total mortality												
	30.6	42.8	20.4	18.2	32.7	27.3	6.1	2.6	10.2	9.1	100.0	100.0

1/ Percent of 1925 stand.

Table 11.- Fifteen-year mortality in the cut-over stand, by causes. Percent[1] of number and volume b.m. killed by different agencies, 1925-1940. Sample Plot S7, 160 acres.

D.b.h. class	Lightning		Wind		Bark beetles		Mistletoe		Unclassified		Total	
	No. trees	Volume b.m.	No. trees	Volume b.m.	No. trees	Volume b.m.	No. trees	Volume b.m.	No. trees	Volume b.m.	No. trees	Volume b.m.
Inches	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
12-20	0.5	0.8	0.2	0.2	0.1	0.2	0.4	0.4	0.5	0.4	1.7	2.0
21-30	4.1	4.4	1.3	1.2	0.6	0.9			0.6	0.8	6.6	7.3
31+			7.7	6.6							7.7	6.6
12+	1.3	2.6	0.5	1.2	0.3	0.6	0.3	0.2	0.5	0.6	2.9	5.2
Percent of total mortality												
	44.8	50.0	17.2	23.2	10.4	11.5	10.4	3.8	17.2	11.5	100.0	100.0

1/ Percent of 1925 stand.

Table 12.- Periodic annual net increment in volume per acre and in in percent[1] in virgin and cut-over stands. 1925 to 1940.

Forest	1925 to 1930		1930 to 1935		1935 to 1940		Mean 1925 to 1940	
	Ft.b.m.	Pct.	Ft.b.m.	Pct.	Ft.b.m.	Pct.	Ft.b.m.	Pct.
Virgin	76	0.65	67	0.55	3	0.02	48	0.41
Cut-over	98	2.90	96	2.48	96	2.20	96	2.84

1/Percent of total volume at beginning of period.

Table 13.- Increment and mortality by 5-year periods in a virgin stand of ponderosa pine, 1915 to 1940.

	Annual increment or loss in board feet per acre				
	1915-20	1920-25	1925-30	1930-35	1935-40
Gross increment	124	139	116	106	102
Mortality	41	107	50	40	112
Net increment	83	32	66	66	-10
				20 yrs.	25 yrs.
Mean net increment in board feet per acre				62	47
Mean net increment percent				0.57	0.43